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NOTES ON GOLD HILL AND VICINITY, TOOELE COUNTY, WESTERN UTAH.

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In 1891 E. E. Olcott, E.M., collected a suite of specimens of rocks along the old stage road which passed westward through Dugway, Fish Spring Camp and Clifton, Utah, and so on across the state line to the headwaters of Deep Creek, Nevada. While at Clifton, Mr. Olcott made a short trip to the north and visited Gold Hill and the neighboring Cane Springs mine. The specimens collected were placed in the hands of J. F. Kemp for determination and as several proved to be of much interest, and as all came from a portion of the county regarding which records were few, a short contribution was prepared and published regarding them.[2] Clifton and Gold Hill are two early mining camps formerly scenes of activity, quiet in later years, but now revived into active production of copper ores. There was once a small smelter at the former, whose slag dumps and old flue leading up hill could still be detected in 1908 at the time of the senior writer's visit. Much placer work in the mantle of re-

[1] *Note.* The earlier pages are by the senior writer, J. F. Kemp; the later pages, as recorded in a footnote, are by the junior writer, Paul Billingsley.

[2] J. F. Kemp, Notes on several rocks collected by E. E. Olcott, E.M., near Gold Hill, Tooele County, Utah. *Trans. N. Y. Acad. Sciences,* 11: 127–128, 1892.

In this paper, Cane Springs (so named, as has been subsequently learned, from the cane-like reeds growing near) was spelled by mistake Kane Springs.

sidual products had been done in old days on the slopes of Gold Hill. Modest deep mining had been developed at the Cane Spring and Alvarado claims and a small stamp mill had been early erected to treat the ore. Some ancient machinery and the tailings dump were still discernible in 1908. In the years just preceding 1908 more extensive underground explorations and development had been carried on at Gold Hill and have been recently increased, as more fully described subsequently by the junior author. A shaft had also been sunk by the owners of the Cane Springs mine at the Alvarado mine about two miles from the Cane Springs openings, and a mile north of the workings at Gold Hill. Both the Cane Springs and Alvarado deposits possess some special points of interest in that they yield native gold in vesuvianite and zoisite in contact zones produced by granite from limestone. As is now generally known from the researches of recent years, iron or copper ores with little of the precious metals are the usual though not invariable ones in these geological associations. Variations of the type have some special claims of interest. Between Gild Hill and Clifton, at the Lucy L. claim, some gold had been discovered in association with native bismuth.

The rocks gathered by Mr. Olcott proved to be rhyolite from Fish Spring Camp; hypersthene-andesite between Fish Spring Camp and Dugway; biotite-andesite with hornblende, from an outcrop two miles east of Rockwell's Ranch, Cherry Creek; hornblende-granite from Clifton Mountain near Gold Hill; and a specimen of special interest, which primarily led to this further contribution. It was finely crystalline, black in color, with a few very small, shining, prismatic crystals, and was thought to be basalt when collected. The locality was given as the Cane Springs mine, but on examination with the microscope the rock proved to be an andalusite hornfels of singular perfection. After determining and briefly describing the hornfels in 1892, the senior writer hoped for years to visit the locality and was finally enabled to do so in 1908 while on a trip to Nevada over the then just constructed Western Pacific Railroad, with his old

student and friend, Mr. Kingdon Gould, to whom acknowledgments are here gladly expressed for the opportunity. Meantime, before a full account was prepared, the developments for copper at Gold Hill had been examined by the junior writer and the plan of a joint paper was adopted.

There are a few early references to the geology of this region; S. F. Emmons has recorded some notes in Vol. II., p. 475, of the Survey of the Fortieth Parallel, since the region lay in his area. Mining interest developing in the early nineties in the Deep Creek region of Nevada, brought the veteran mining geologist, W. P. Blake, into the district and prompted his sketch entitled "Age of the Limestone Strata of Deep Creek, Utah."[3] One of the Basin Ranges, the Ibapah, runs along the border of Utah and Nevada and consists largely of limestones which Professor Blake regarded as Lower Carboniferous because of the specimens of *Productus* contained in them. The limestones are pierced by granite and other igneous rocks, which have wrought extensive contact metamorphism and have caused the formation of some interesting minerals briefly noted by Professor Blake. Obviously, as the andalusite hornfels demonstrates, shales are also affected.

Cane Springs, Gold Hill and Clifton are situated in a group of hills or low mountains usually called on the maps the Clifton Hills. A series of sharp peaks lying between Gold Hill and Cane Springs furnish the chief elevations, but the country in general is rough and deeply incised by erosion. The general geographical position is shown in Fig. 33.

While Clifton and Gold Hill were formerly only visited by way of the stage road from the east across the alkali desert, the construction of the Western Pacific Railroad and its branch to Gold Hill south from Wendover have made them much more accessible. In 1908 they were reached by wagon road from Wendover, the last station in Utah before the railroad crosses into Nevada. Wendover is on the western rim of the Bonneville

[3] *American Geologist* for January, 1892, p. 47, which was reprinted in the *Engineering and Mining Journal*, February 27, 1892, p. 253.

basin. The wagon road followed the gravel benches southward, just above the alkali flats, which also can be traversed by teams after a long series of dry days. Should a shower fall,

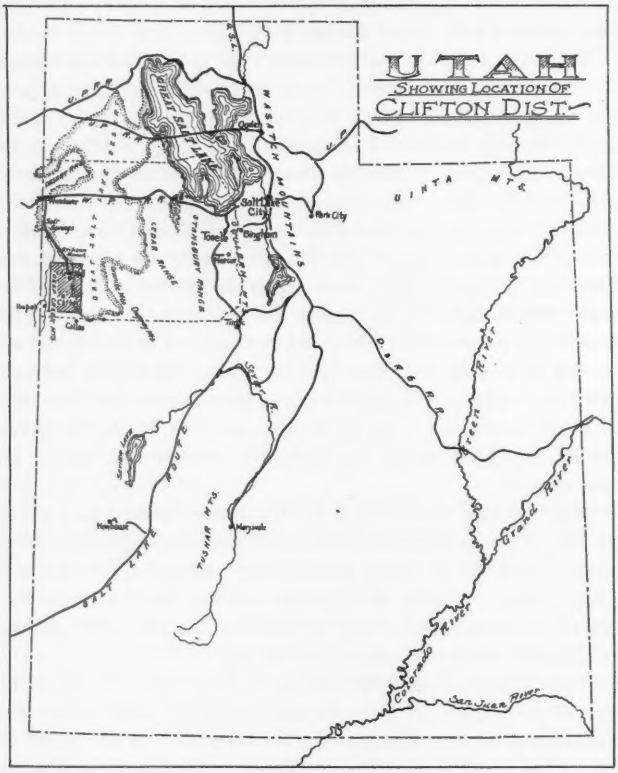

FIG. 33. Map of Utah showing the location of the area described, in western Tooele County.

however, the flats become so soft that they make a very heavy track for some time thereafter.

Some fifteen or twenty miles south of Wendover very large,

warm and slightly alkaline springs come out at the foot of a flow of basaltic rock. The water is sufficient in amount to form a series of ponds, some acres in extent and up to six or eight feet deep, as it flows eastward to be lost in the alkali flats of the Bonneville depression. The ponds are called the "Salt Lagoons" upon the large map of Lake Bonneville in Monograph I. of the U. S. Geological Survey on Lake Bonneville, by G. K. Gilbert. The text of the monograph contains but little descriptive matter upon the western border of the basin, and the Salt Lagoons escaped attention. The same is true of Volume II. of the Survey of the Fortieth Parallel. The springs were evidently an old-time resort of the Indians, since chipped obsidian flakes and imperfect arrow-points are scattered about. The lagoons are also provided with small fish, with prominent dorsal fins and spines. The fish quite fearlessly nibble at the feet of a swimmer. The waters must derive their heat from some not yet exhausted store in the igneous rocks of the neighborhood. Whether the water itself comes from the same source is a question not capable of demonstration. One may only record that the region is arid and the flow of water is copious and somewhat alkaline. It is not disagreeable to the taste and is freely taken by cattle, but is said to be an aperient in its medicinal properties.

The Last Chance ranch, whose owner, Mr. John A. Erikson, drove the senior writer south from Wendover, lies on an adobe terrace in Utah where Deep Creek, flowing northeast from the mountains in Nevada, crosses the state line and passes out upon the alkali flats to the east. In times of high water it gives a sufficient supply for irrigation and makes possible two or three crops of alfalfa and a productive orchard. In the dry season the water fails, but there is enough in the wet season. The post-office is Ibapah, Nevada, twenty miles or so away to the southwest in the Deep Creek Valley, where also are the nearest ranches. A mile and a half from the ranch upstream, Deep Creek pours for a quarter of a mile through a narrow gorge in a flow of pink, tuffaceous rhyolite. The fall is about 140 feet, and the opportunities for the storage of water with a dam are

excellent. The irrigation of a moderate area would thus be made possible below the gorge.

The flow of rhyolite is of much interest. It is so slaty as to strongly resemble a pink shale. It is tilted exactly like a sedimentary rock and has dips up to 45 degrees to the northwest and north, with a varying strike of northeast and east, magnetic. The flow contains many streaks of black obsidian spherulites, blow-holes with secondary quartzes, and the usual phenomena of lithoidal rhyolite. There is one striking development of columnar structure, but the prominent joints, one set northeast and the other northwest, are more in evidence. The creek in its gorge swings from one set to the other, so that its course is not straight. There are several hundred feet of the rhyolite exposed, a rough estimate being three hundred.

Five or six miles south of the Erikson ranch is Dutch Mountain, an east and west spur of the main Deep Creek range. Dutch Mountain and its eastern peak, locally called Mt. Wilson, consist of upturned quartzites and limestones, presumably Carboniferous in age. On the northern side of Dutch Mountain a tunnel 800 feet long in 1908 had been driven south across the quartzites by the Garrison-Monster Co. The quartzites with two streaks of slate had a strike of N. 40° E. mag. (N. 57° E. true) and a dip of 40° east. The tunnel yielded a good flow of cool, soft water, which was used both by the miners and at the ranch for drinking purposes. To the southeast, across the strike of the quartzites and apparently resting upon them, lies a blue limestone. At a mile or more southeast from the tunnel a prospect in lead-silver ore had been earlier opened in much-crushed limestone. It is known as Wilson's mine. The vein runs east and west magnetic (N. 73° W. true) and dips 60° north. Above it the limestones strike N. 35° W. magnetic (N. 18° W. true) and dip 35° W., so that there has been a marked change from the strike and dip of the quartzites. Obviously, some very interesting geological structure could be worked out, but the senior writer could only spend a few hours on the mountain and had to let it pass. No fossils were seen, but the general

association of strata is much like that in Bingham Cañon. In the absence of fossils one should only remark the probability. Further search may bring the remains of organisms to light.

In going from the Erikson ranch to Cane Spring and Gold Hill, one drives ten miles southeast around the spur of Dutch Mountain so as to strike the northeast and southwest valley which bounds Dutch Mountain on the south. The road skirts the alkali flats which lie to the eastward, keeping to the gravelly terraces which here, as everywhere in the arid regions, surround the mountains. The road then turns southwestward about the arid regions. The road then turns southwestward about five miles to the old Cane Spring mill. The observer soon becomes aware that granite has replaced the sediments of Dutch Mountain, both from the loose boulders and from the ledges, which project above the abundant wash. The granite, however, near the mines is succeeded by limestone and slates, with very interesting contact zones.

The old and now dismantled mill of the once active Cane Spring mine stands at the foot of a ledge of blue limestone, which gives abundant evidence of severe crushing. It is rusty and while, in general, dips and strikes are very obscure, a reading of N. 45° E., 70° N., magnetic (N. 62° E., 70° N. true) was made on a shaly streak. The dump from the old mill, of crushed calcite and contact minerals, runs away to the east in such amount as to indicate protracted operation in former times. There is also evidence of some small smelting work, as shown by slag and old machinery.

A few rods south of the mill is the boarding house, occupied at the time of the senior writer's visit in 1908 by several hospitable brothers named Woodman. The mill had been fed by two small mines, the Cane Spring, about a mile on the far side of a ridge to the west, and the Alvarado, nearly a mile to the east and on the far side of another ridge in this direction. Both are located on contact zones produced from the blue limestone by intrusive granite. Some notes on the mineralogy will be later given.

From the old mill and boarding house the blue limestone runs

to the southwest in a ridge for about a quarter of a mile (see Fig. 34). It is badly crushed and affords few opportunities for satisfactory dips and strikes. One quartz vein with a strike N. 25° W., magnetic, was observed. Both to the west and south the limestone gives way to black slates, whose presence in place

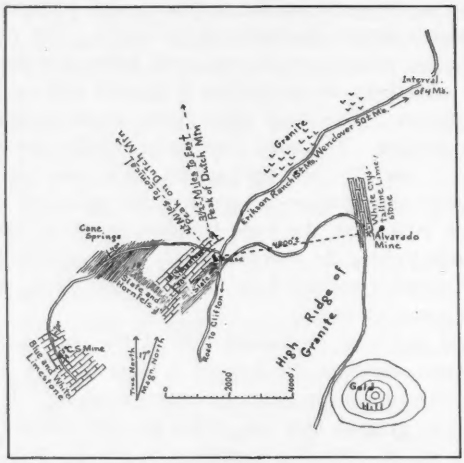

FIG. 34. Sketch map, illustrating the geology at the Cane Spring and Alvarado mines.

is shown chiefly by the loose pieces on the surface. In this belt the andalusite hornfels is found, but the andalusite crystals are so small that the variety of slate which has them cannot be easily identified without the aid of the microscope. Farther westward the slate is replaced by the limestone in which the Cane Spring mine is located. Granite outcrops to the south of the Cane Spring mine, but the mass which is the immediate cause of the contact effects in the slate is not visible, and is presumably beneath the surface at no great distance.

The geological relations are sketchily shown in Fig. 34, a small map based on one afternoon's observations. The large geological features are much more extensively given in the map by

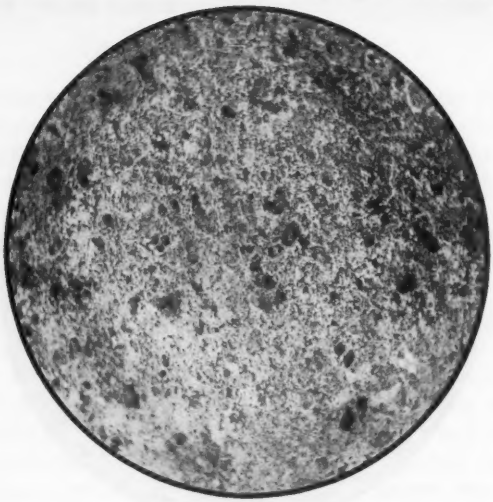

FIG. *A*.

Photo-micrograph of least altered shale. Black, carbonaceous particles are set in a fine-grained mass of kaolinite and quartz. Actual field 0.15 in. or 4 mm.

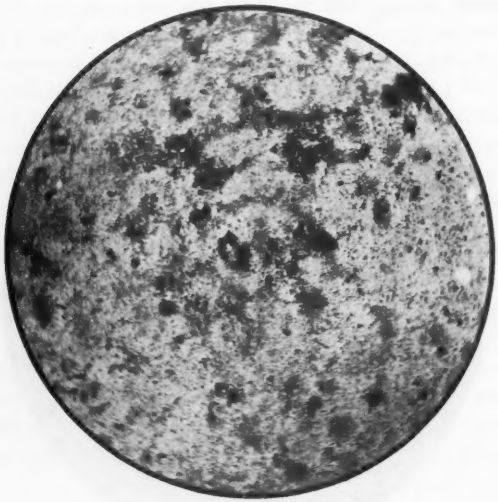

FIG. *B*.

The carbonaceous matter begins to segregate under contact influences. Same scale.

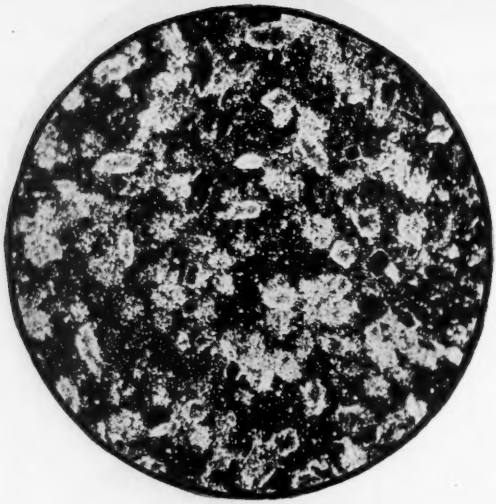

FIG. *A*.

Minute brown biotite appears in the dark groundmass, and rude beginnings of andalusite mark a further stage in contact effects. Actual field 0.15 in. or 4 mm.

FIG. *B*.

Andalusite hornfels with sharp, clear chiastolites. Same scale.

the junior writer (Fig. 37). The distance from the house to the Alvarado mine was scaled off at 4,500 feet from a claim map possessed by the brothers Woodman. Using this as a rough base line and the house and mine as observation points, the bearings on the two peaks of Dutch Mountain were read and plotted with the results in distances as recorded. Much of the bed-rock geology near the house is concealed by wash.

Reserving the Alvarado mine for some special details later, a few words may be given to the altered slates and the interesting associations of gold in the Cane Spring workings.

The slate, where not visibly altered, is a normal variety of this familiar rock. The minute grains of quartz are set in a somewhat indefinite mass, believed to be kaolinite and carbonaceous particles (Plate XVII., *A*). The first effect of the granite is shown in the aggregation of the carbonaceous matter into blotches which form a mosaic with clearer spots between (Plate XVII., *B*). Little brown spots of biotite next develop, sometimes in the midst of rude outlines of andalusite crystals, sometimes without the latter (Plate XVIII., *A*). The andalusites gradually assume more and more definite outlines, until sharp, square prisms, with the curious characteristic inclusions of carbonaceous matter, are the last result (Plate XVIII., *B*). The prisms are small, being less than 0.1 inch (2.5 mm.) long and a sixth as broad, but they are sharp, clear and perfectly fresh. The frequent change to mica, which makes so many cases of andalusite very unsatisfactory for study, has here failed to develop, and the clear portion of the crystal which surrounds the black inclusions exhibits sharp cleavage cracks and excellent optical properties. The shape of the included mass of black coloring matter, presumably graphite, can be easily made out, from many sections, such as are shown in a photomicrograph in Plate XVIII., *B*. Two thin, diagonal sheets of the black flakes invariably run from end to end of each prism. Besides these and embracing them in part, there are, of the black substance, two slender square pyramids whose apexes meet in the middle of the crystal and whose bases are at its flat ends where they

nearly fill the entire cross-section. The sketch shown in Fig. 35 is compiled from the cross-sections, and differs in details from the familiar ones of the Lancaster, Mass., andalusite given in Dana's mineralogies and in the textbook of Moses and Parsons, and from foreign cases illustrated in the works on microscopic mineralogy.

Good cases of andalusite contact zones for petrographic study are not very common in North America, despite the great development of intrusive masses. Large, but rude chiastolites are

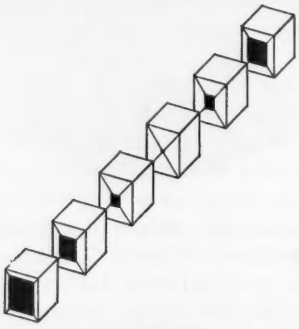

FIG. 35. Diagram of an andalusite crystal, as compiled from numerous thin sections. The actual crystals are about 0.1 in. or 2.5 mm. long.

found in the slates of the Crawford Notch in the White Mountains of New Hampshire; and more perfect large ones, which have reached all the mineral cabinets, have made Lancaster, near Worcester, Mass., a very famous locality. There are others in Nova Scotia and in California, but satisfactory examples are sufficiently rare to justify the descriptions and illustrations here presented. Andalusite has been shown by petrographers in later years to have some special claims to interest. Together with sillimanite and cyanite, it forms a little group of three minerals, all of which have the same composition, Al_2O_3, SiO_2. The specific gravities are, however, quite different.

Andalusite	3.16–3.20
Sillimanite	3.23–3.24
Cyanite	3.50–3.67

Students of rocks have therefore inferred that cyanite would be formed in deep-seated zones where very great pressure might serve to compact the molecules, whereas sillimanite and andalusite would develop under less pressure and at depths nearer the surface. Andalusite and sillimanite are more characteristic of contact zones than is cyanite. We might perhaps infer that the zone at the Cane Spring mine was developed at but moderate depth.

Both the Cane Spring and Alvarado mines have been sunk upon mineral aggregates having all the characteristics of contact zones, although only at the latter is the intrusive rock visible near the ore. Cross-sections of both mines by the junior writer are given in Fig. 41. The wall-rock at the former is a bluish crystalline limestone which below the mine gave a reading of N. 70° W., mag. (N. 53° W., true). The mine workings a short distance above ran about N. 45° W., 55° E., mag. (N. 28° W., true). They were based on a streak of copper-stained, silicated and quartz-bearing rock, believed to be produced from the limestone by some igneous rock, presumably granite, but not exposed near the ore. A thin section of a specimen from the excavation revealed as its principal component a colorless or whitish, transparent mineral, with a very marked rectangular cleavage, parallel extinction and interference colors of a very low order. Optical tests prove it to be vesuvianite, with which is associated zoisite, a little tremolite and garnet, and a very little quartz and calcite, the last two of late introduction. The identification of both vesuvianite and zoisite has been verified by the senior writer's colleagues, Dr. C. P. Berkey and Mr. R. J. Colony, to whom thanks are here expressed. The two minerals look so much alike that close work is required to distinguish them.

In the excavations molybdenite is also decidedly in evidence and supplies another characteristic, although usually a minor mineral of the contact zones. The lime-silicate rock contains scattered, small, irregular masses of chalcopyrite, and where these have become oxidized the usual green and blue stains appear, with some rusty streaks of limonite. A small piece of ore was given

the senior writer by the Messrs. Woodman in which irregular bits of native gold can be readily seen in the midst of the white, finely granular lime-silicates, presumably vesuvianite and zoisite; but the specimen is too small to be sectioned without destroying it. Rusty cracks also run through it and in them gold can likewise be detected. The latter gold may have been once contained in chalcopyrite or pyrite, but the larger development of the yellow metal is in clear, unstained silicates. The gold was precipitated in, or with them, without any associated sulphides.

At the Alvarado mine an inclined shaft had been sunk in 1908, in white, crystalline limestone, on a slope of about 60 degrees, to an estimated length of over 200 feet. Drifts had been driven each way on two levels and stopes up to 15 feet across had been mined out. On the second level an easterly cross-cut had encountered porphyritic granite. Geological cross-sections of both these mines, by the junior writer, are subsequently given.

Gold is sometimes visible in the native form, and is associated with zoisite; acicular tremolite, the needle spar of the miners; with a clay-like gouge; with reddish chalcedony; and with hard serpentine. Green stains of malachite are frequent. Thin sections reveal the same prismatically cleaving mineral as at the Cane Spring mine. In the present instance it has been identified as chiefly zoisite. Fig. 36 has been sketched from a slide, cut so

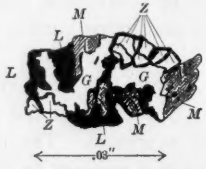

FIG. 36. Enlarged sketch of two fragments of native gold. *G*, gold; *Z*, zoisite; *M*, malachite, staining zoisite; *L*, limestone.

as to preserve a bit of gold. Beside the zoisite, vesuvianite has been detected, and a very little tremolite and garnet. Quartz of late introduction and secondary malachite and limonite are recognizable. The serpentine mentioned above is shown by the

microscope to have been derived from tremolite, whose acicular habit is still preserved. Chalcedonic silica has been introduced, as has also calcite.

The little fragment of gold, illustrated in Fig. 36, is about .03 of an inch or a little less than a millimeter in longest dimension. It is irregular in outline, angular and bordered either by a rim of limonite or by malachite, staining zoisite. The natural inference is that the gold was originally precipitated in association with some copper-iron sulphide, such as chalcopyrite, and that it has been freed by the oxidation of the sulphide. That at least some slight amount of copper should accompany the gold in the contact zone is in accord with the usual experience, copper and iron being our most frequent metals in these surroundings. Visible gold is not often in evidence in the zones, but one case has been previously observed by the senior writer, namely, at Aranzazu, near Concepcion del Oro, Zacatecas, where, in association with garnet and other lime-silicates, a little fleck of gold is rarely observable. The Aranzazu zone has been described in detail by Alfred Bergeat[4] following a visit to the mines of a party from the International Geological Congress of 1906. One is also reminded of the Nickel Plate mine of southern British Columbia, where the gold, the chief value, is associated with arsenopyrite in a contact zone from limestone.

Gold Hill, about a mile south of the Alvarado mine and next to be described by the junior writer, was originally developed by surface gold-washings on the weathered outcrop of what has proved to be a copper deposit in depth.

The granite, often referred to above, is a red variety with both orthoclase and plagioclase in relatively varying amounts, sometimes one and sometimes the other being in excess in the slides. Quartz is inferior to the feldspar in amount, so much so that one infers that the granite contains silica in the lower percentages shown by this rock, and probably not much if at all above 65. Both brown biotite and green hornblende are well-

[4] Alfred Bergeat, *Neues Jahrbuch*, Beilage Band XXVIII., 1909. Also republished in the *Boletino Instituto Geologico Mexicano*, No. 27, 1910.

developed components, sometimes one, sometimes the other being in excess. Magnetite is rather abundant as granites go, but apatite does not fail. In the slides the largest crystals reach 0.1 of an inch or 2.5 mm. Strain shadows are shown in the rims of quartzes. Next the limestone in the workings of the Alvarado mine the texture is porphyritic; but at a distance from contacts it is the normal texture of granite. The rock is thus practically a granodiorite as is so frequently the case with the western intrusive masses.

A few additional notes on the district farther south may be recorded by the senior writer, before Gold Hill is taken up in detail by the junior. On the road from Gold Hill south to Clifton, one passes the Lucy L. property, whose tunnel is driven in development of a quartz vein, carrying gold in association with native bismuth. Although pressure of time prevented a visit to the underground developments, several specimens were presented by Mr. Clyde Wilson, then in charge. One gives excellent tests for bismuth with the blow-pipe, and is undoubtedly the native metal. Another specimen afforded the characteristic and unmistakable test for tellurium and sweated under the blow-pipe little beads of gold. Traces of lead and antimony were also indicated. The mineral is a silvery, thin-bladed, brittle variety and would suggest a telluride or stibnite to an observer. This new locality for telluride of gold is of interest. For the blow-pipe corroborations, acknowledgments are due to Dr. Charles P. Berkey.

At Clifton granite appears on the east, exhibiting evidences of crushing and decomposition. It has been mineralized along crushed zones with copper minerals and some arsenopyrite. The crushed zones have an iron cap. Along the stage road to the west and a little way from the houses of Clifton, blue limestone, much brecciated and crushed, appears. The limestone contains crinoid stems and a few poorly preserved corals, an inch long and conical in shape. A few miles across the divide to the west, and south of the stage road, several prospects had been opened on crushed zones in granite. At one, minerals of arsenic and copper were observable and at another galena.

FIG. *A*.

View of Clifton Basin in granite, looking south to Montezuma Peak of carboniferous limestone.

FIG. *B*.

Deep Creek Mountains in background, looking west across valley of Deep Creek, from western slope of Dutch Mountain. Deep Creek flows into Bonneville Basin at the right, and beyond the photograph cuts the rhyolite flow, earlier described, and passes the Erikson ranch.

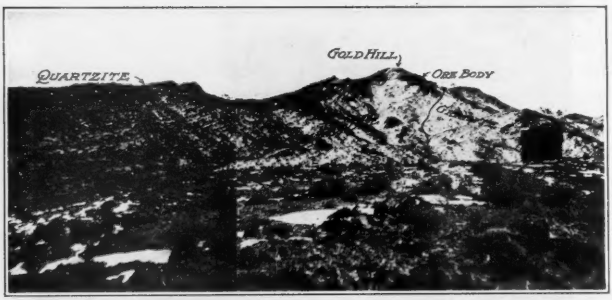

FIG. *A*.

View of Gold Hill from the northwest.

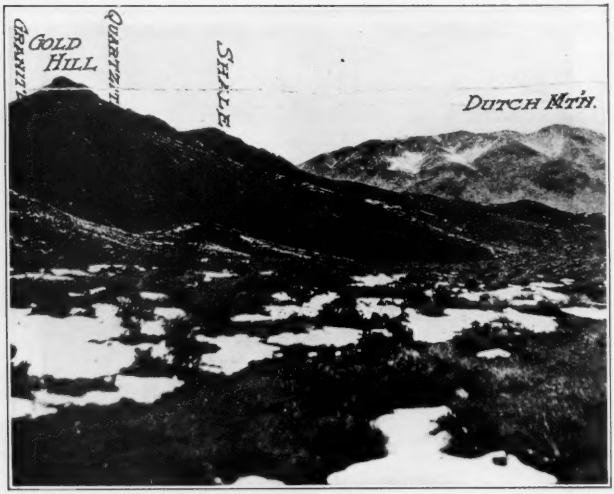

FIG. *B*.

View of Gold Hill from the south.

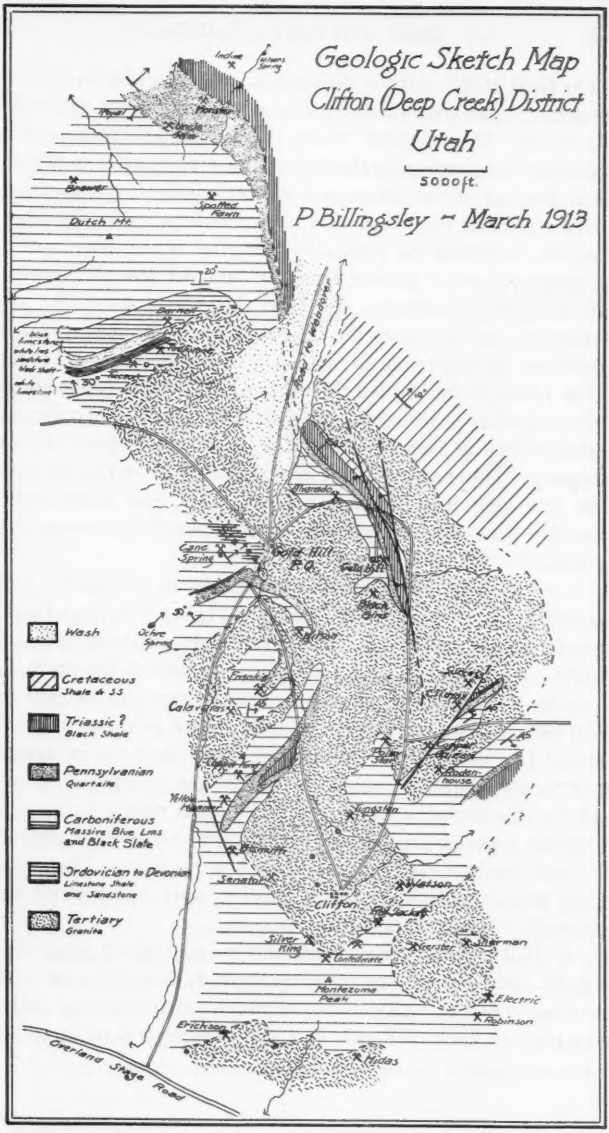

FIG. 37. Geological map of the Gold Hill district, embracing the area shaded in Fig. 33.

The Gold Hill,[5] which is the chief mine of the Clifton district, lies about a mile southeast of the Alvarado, and about two miles east of the old settlement where the Woodman brothers live. For some time previous to the visit of the junior writer in March, 1913, development at the mine had been vigorously prosecuted. Adverse physical conditions and lack of transportation facilities, however, prevented the profitable operation of the mine, and in the spring of 1913 it lay idle, awaiting the much discussed branch railroad from Wendover. In 1916 this was constructed and during the past two years the Gold Hill mine has been a steady contributor of copper ore to the International Smelter at Tooele.

The junior writer visited the mine, and incidentally the entire Clifton district, as assistant to Mr. F. A. Linforth, his colleague in the Geological Department of the Anaconda Copper Mining Company. Observations were made, and notes taken in common, following joint discussion on the field, and acknowledgments are here due Mr. Linforth for his permission to use this material.

The relation of the Gold Hill ore deposits to the general geological features of the district appears in Fig. 37. A rim of sedimentary rocks, mainly limestone, surrounds an inner basin of granite. To the north, at Dutch Mountain, and to the south, at Montezuma Peak, this rim rises to the respectable heights of 8,000 feet or more. The granite itself forms no eminences, but residual fragments of its sedimentary cover stand up in irregular groups of hills. From the contacts now exposed it is evident that the intrusive top of the granite was nearly flat, and it is further apparent that the present erosion surface throughout the inner basin nearly coincides with this plane. The more deeply incised valleys are all in granite, while the hilltops are universally of sedimentary rock.

Gold Hill is the southern termination and highest point of a ridge of such sedimentary formation, which extends as an easterly dipping belt of well-defined limestones, quartzites and shales from the east flank of Dutch Mountain for several miles to the

[5] From this point on the text is by Paul Billingsley.

southeast. The ridge is underlain by granite, which appears on both slopes, and it may be regarded as a roof-pendant partially submerged in the intrusive rock.

By correlating the formations which can be observed on Dutch Mountain and Gold Hill, it is possible to determine the following stratigraphic column:

Top Age.	Formation.	Thickness (Est'd), Feet
Cretaceous	Yellow shale and sandstone	1,000 plus
.....	Unconformity	
Triassic ?	Black shale	500
	Dark sandy shale	300
Carboniferous	Buff quartzite	200
	Impure sandy limestone	200
	Massive blue limestone	2,500 more or less
	White limestone	500
	Sandstone	500
	Black shale	300
	Sandy shale	200
Devonian ?	White limestone	1,000 plus
Bottom		

This section fails to agree in detail with any of the recorded stratigraphic columns of Utah or Nevada, but in a general way is comparable to the Carboniferous succession at Ely, extending upward, however, into higher horizons than are there found.

The Gold Hill ridge is composed of the upper 500 feet of Carboniferous formations and as much more of the overlying Triassic (?) black shales. Most prominent topographically is the quartzite, which has been placed at the top of the Carboniferous. As shown in the accompanying photographs this forms the backbone of the ridge, and its tawny, polished outcrops, with characteristic "desert varnish," form an excellent geologic horizon marker for even long-distance observations. The underlying limestones outcrop less boldly, but show, along the course of the ridge, many bare rock surfaces, and their light color makes a readily traced band along the western slope of the ridge. The overlying black shales, on the east slope, do not outcrop at all, but form a steep talus slope of dark hue.

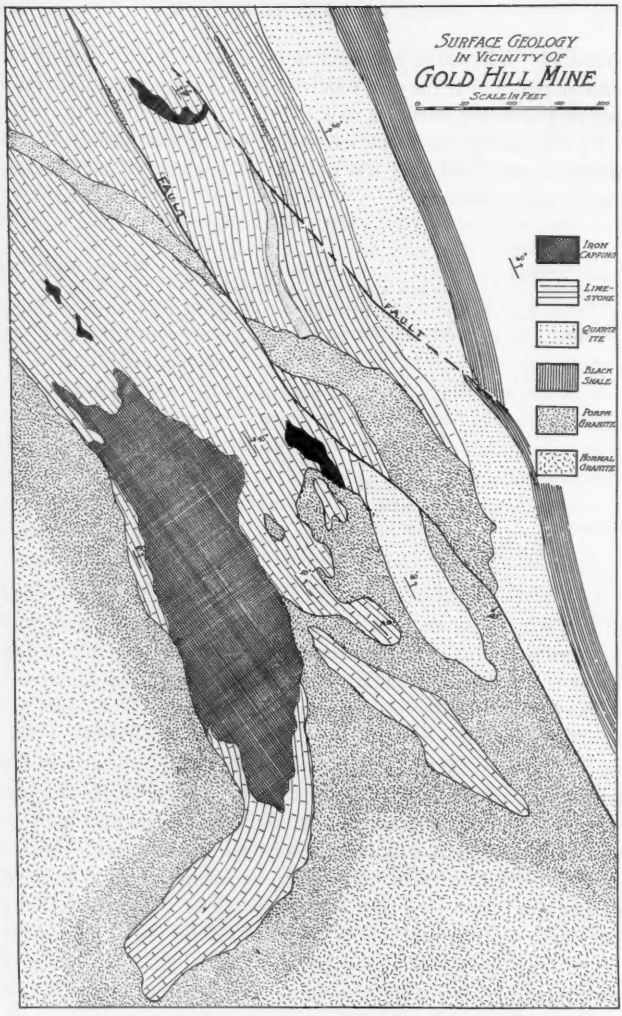

FIG. 38. Surface geology in the vicinity of the Gold Hill mine.

As can be seen from the accompanying surface map (Fig. 38) and cross-section (Fig. 39), the ore-bodies of the Gold Hill mine are found within the limestone member of the succession, at a point where it is most intricately cut and enveloped by the intrusive granite. The two figures show sufficiently well the extremely irregular contact. The granite is normally the rather basic, coarse-grained type described above by the senior writer,

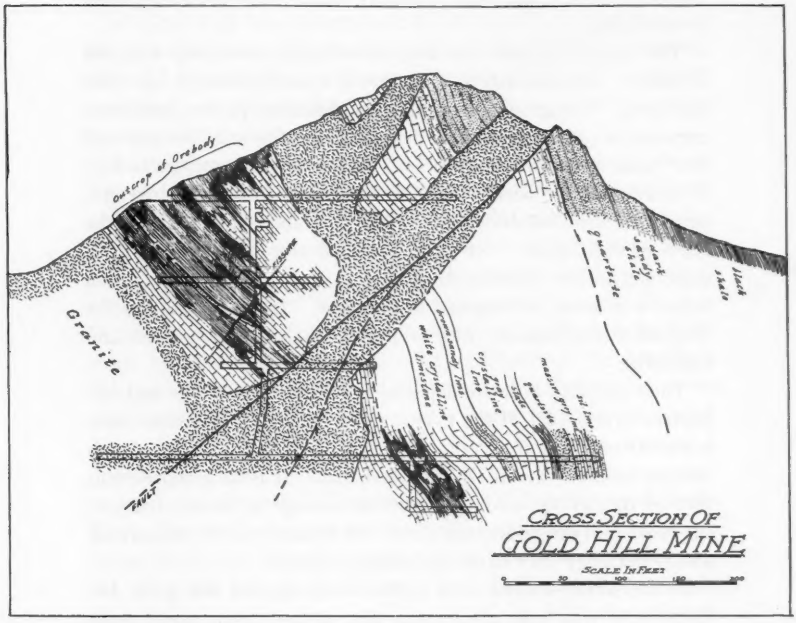

FIG. 39. East and west cross-section of Gold Hill mine.

but near the contact, and in the smaller masses, it becomes fine-grained and even more basic, with well-developed plagioclase phenocrysts. Indeed, some observers have attempted to differentiate this porphyritic phase from the granite, considering it a

subsequent intrusion. The gradation from the one to the other, however, is so apparent, both on the surface and in the mine, that there can be no doubt that the so-called porphyry is merely a contact phase of the normal granite. The effects of the intrusion upon the somewhat varied sedimentary series are comparatively slight. Recrystallization of the limestone is general, to be sure, but there is little or no development of the characteristic contact minerals, and even obviously impure beds show no garnet or tremolite.

The ore-bodies, too, are not immediately associated with the contacts. Occasionally a contact will exhibit a bit of cupriferous pyrite, intergrown with quartz, calcite and garnet, but much unprofitable prospecting has demonstrated the small extent and low value of such occurrences. The important mineralization is found entirely within the limestone, and consists, at present, of porous iron oxides, carrying copper, and some lead, in the form of carbonates. No sulphides whatever remain, desert climate and hilltop location combining to carry complete oxidation below any levels yet reached in the mine. In all probability the original mineralization was of pyrite, chalcopyrite, galena and sphalerite.

Thus the Gold Hill ore-deposits fall within a familiar and important group, that of the pyritic replacements of limestone near a granite or monzonite contact, a group found at its widest development in the Warren District, Arizona. It is as a representative of this group, adding to our knowledge of its habits, that the Gold Hill ore-bodies are chiefly of interest, for in occurrence and mineralogy they have few unique features.

In the writer's mind such replacement deposits are quite distinct from true contact-metamorphic deposits, the latter term applying rather to ores wherein ore minerals and contact-metamorphic silicates are of contemporaneous formation. In the Warren District, where both types are found, the differentiation is readily made, and a time-succession of events can be established thus:

1. Intrusion of Sacramento Hill porphyry, accompanied by

addition of quartz, sericite, pyrite and hematite to nearby limestone.

2. Silicification of more remote limestones.

3. Brecciation of such silicified limestone.

4. Pyritic replacement of portions of limestone outside of intensely metamorphosed zone 1.

5. Copper mineralization (chalcopyrite and bornite) in veinlets within and adjoining pyrite masses.

At Gold Hill the subsequence of the pyritic replacements to the contact-metamorphic mineralization cannot be thus definitely proved, but the distinction between the two types, and the greater remoteness of the replacement bodies from the contact, render it extremely probable.

Another general characteristic of the group, in which also it differs from true contact-metamorphic deposits, is the evidence of selective action by the mineralizing solutions. In every district in which such ore-bodies are found, certain horizons prove either more permeable, or more soluble, or both, to the solutions, so that the deposits are largely confined to them. In the Warren District the middle Escabrosa limestone and upper Martin limestone; in the Georgetown District (Montana) the Hasmark Magnesian limestone; and at Cananea the Puertecitos limestone —to mention a few examples recently impressed upon the junior writer—are such favorable strata. The difficulty of drawing a general rule from such instances, however, lies in the fact that the most varied qualities are found in the different favored beds. Thus, the middle Escabrosa is a rather thin-bedded limestone, often cherty; the Martin is thin-bedded, silicious and dolomitic; the Hasmark is a good dolomite; and the Puertecitos is dark, thick-bedded and often cherty. At Gold Hill the selected stratum introduces still another variety, being, as readily seen on the cross-section (Fig. 39), the most massive and pure member of the limestone series.

The localization of the ore-bodies in more or less limited masses within the favorable bed requires the agency of another factor, which was first forced upon our attention at Gold Hill,

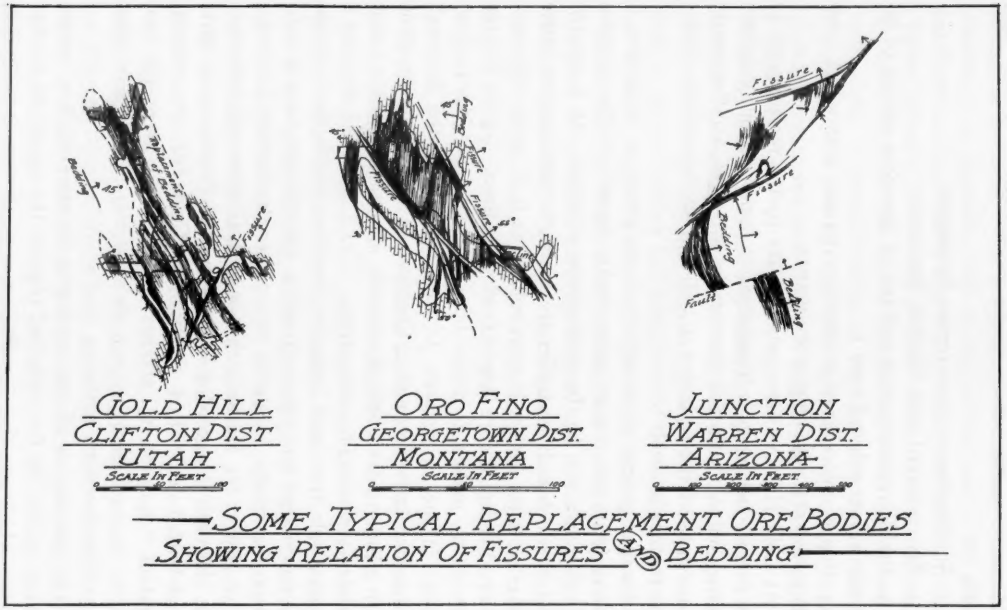

FIG. 40. Some typical replacement ore bodies showing relation of fissures and bedding.

and has since proved of great assistance in the prospecting of similar mines. This factor is the presence of fissures, cutting across the bedding of the formations, and acting as channels for the introduction of the mineral solutions (see Fig. 40). These fissure are seldom lines of displacement, being merely cracks through the limestone, and where they are unmineralized they are difficult to detect and trace. In favorable strata they may widen out by replacement into prominent veins, but beyond the limits of such ore-shoots they are often the merest knife-edge fracture, and even this may be so re-cemented by secondary calcite as to be invisible. Not infrequently such fissures have acted as channels for descending acid waters, and they then become eroded into irregular cavities. Thus, the accurate mapping of these highly important fissures requires the seemingly absurd correlation of a wide ore-bearing vein at one point with a tiny crack elsewhere, or with a series of open caves at still another place. In the Gold Hill mine the dominant fissure is unusually definite and regular, cutting through the east-dipping limestone with a northeast strike and northwest dip, and its agency in admitting the pyritic solutions into the favorable stratum can be well realized.

As has already been stated, no primary ore minerals are found in the Gold Hill mine. The replacement bodies are now oxidized to limonite, hematite, and (probably) siderite, in open, porous aggregates, and in the interstices of these iron minerals malachite, azurite, cerussite and smithsonite occur. A rather high silver content may be attributed to the lead carbonate, which shows its widespread presence by the trace or more of lead found everywhere in the ore-body. The value of the deposit, however, lies in the copper, which is present to the amount of about 5 per cent. throughout the ore-body. The question arises here, as in so many similar mines, whether the oxidized ore now found has been changed in value by the process of oxidation. In other words, has oxidation been accompanied by a leaching and impoverishment of the upper zone, with enrichment below, or has the ore merely oxidized in place with no secondary

transportation? Development in the Gold Hill mine has reached the point where this problem, always so important in these oxidized replacement ore-deposits, can be answered with some degree of accuracy. The upper part of the replacement body consists of porous iron oxides, and contains very little of either copper or lead carbonate. The edges of the body throughout are lean. The copper minerals are found in a sort of central core, entirely surrounded by barren iron oxides, and are, as already stated, distinctly subsequent to the limonite and hematite. The cerussite is irregular in distribution, forming local areas high in lead, of which the two chief are, respectively, near the surface and near the bottom of the mine.

Some investigations recently pursued by M. H. Gidel, of the Anaconda Company's geological department, on solutions of copper found in the Butte mines, throw light on the copper occurrence at the Gold Hill. The reagents which have affected the copper at the latter are sulphuric acid, derived from the oxidation of the pyrite, and carbonic acid obtained from the surrounding crystalline limestone (largely calcite). The primary copper minerals, attacked by the sulphuric acid, went into solution and remained in solution so long as an excess of acid was present. The limestone, of course, opposed this reaction, acting as a precipitant to the copper solutions. Thus, one would expect to find the copper carbonates near the edge of the ore-body, with the central part leached thoroughly. As has already been seen, however, the reverse is the case. Mr. Gidel's experiments appear to explain this anomaly.

He has found that in the Butte mines, particularly around old stopes where CO_2 is available, the copper solutions contain varying amounts of Cu_2SO_4, $Cu(OH)_2SO_4$, and $Cu(OH)_2CO_3$, of which the first is a solution, and the two latter are precipitates carried as a slime in the solutions. The aggregate is a more or less thick ooze, depending upon the proportion of basic salts, and readily penetrates the interstices of the rocks. Acid waters will, of course, add to the solubility of this material, and none will precipitate in channels where such circulate. In stagnant places,

however, the compounds gradually become dehydrated, and a precipitate of malachite results.

It appears to the writer that some such cycle as this may explain the Gold Hill phenomena. The combination of surface waters, sulphuric acid and carbonic acid might readily result in some such half-way compounds as those found by Gidel; the physical character of the solution of these would permit its saturating the porous limonite mass; continued action of acid surface waters would leach it from the upper and outer portions of the deposit; while in the central core, less subject to this attack, it would gradually precipitate carbonate crystals in the interstices.

This hypothesis leads to the conclusion that the present copper ore-body does not contain all the original copper of the deposit. Some was presumably carried deeper by the acid waters, to precipitate below wherever the carbonate was in excess. In view of the depth of oxidation, and the gradual disappearance of the malachite below the true ore-body, it is unlikely that much copper was carried far enough down to precipitate as chalcocite. It seems, rather, as though all the dissolved copper were eventually caught as carbonate, not to form commercial ore-bodies, however, except where mechanically concentrated as above described. The lead, now irregularly distributed as a carbonate, probably suffered little or no transportation, since the sulphate is insoluble. It may, however, have entered into the hydrated ooze in some such form as $Pb(OH)CO_3$.

The other mines in the Clifton District (for location see Fig. 37) are of interest in completing the types of ore deposition commonly associated with an igneous intrusion. They may be briefly summarized from this viewpoint.

1. True Contact-Metamorphic Deposits:

Gold Hill (outlying prospects only).

These pits show a tight mineralization of quartz, calcite, andradite, magnetite and cupriferous pyrite, along the contact of porphyritic granite with limestone. So tight is the aggregate that little or no oxidation has affected it.

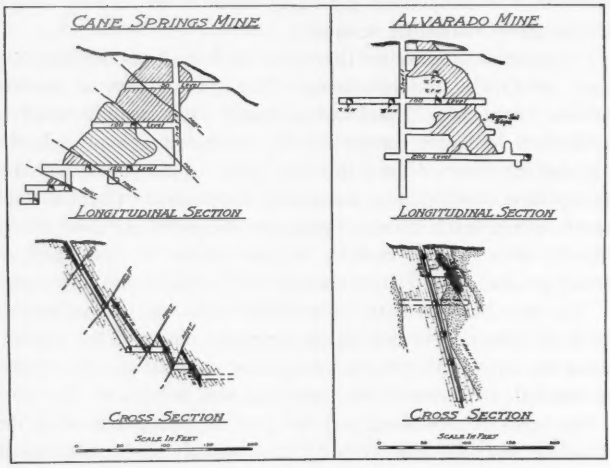

FIG. 41. Cross-sections of the Cane Springs and Alvarado mines.

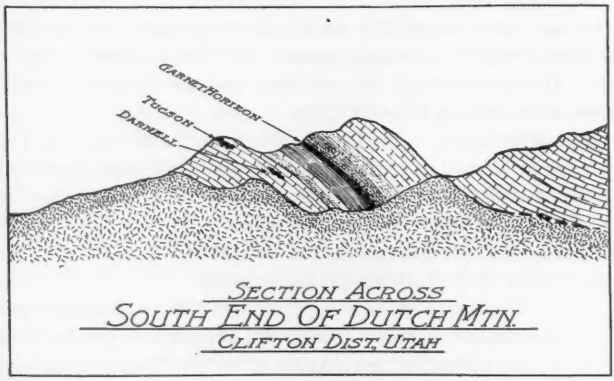

FIG. 42. Cross-section of the south end of Dutch Mountain.

Calaveras (portion).

One shaft on this property discloses an inclusion of highly metamorphosed limestone, entirely surrounded by granite. Its minerals are tremolite, actinolite and garnet, associated with cupriferous pyrite.

Cane Springs.

Alvarado.

Already described by the senior writer.

2. CONTACT REPLACEMENT DEPOSITS:

Gold Hill (main ore-body).

Frankie.

Similar in type to Gold Hill, and found at essentially the same horizon.

Tucson.

Tuolumne.

Darnell.

These are prospects on the south side of Dutch Mountain. The work has been done upon oxidized iron replacement bodies in the lower portion of the great limestone series (see Fig. 42). As at the Gold Hill, this type of mineralization is found away from the intense contact metamorphism. Thus, these ore-bodies are found in a little altered, white crystalline limestone, while a short distance to the north is a bed of nearly solid andradite many feet wide.

3. VEINS IN SEDIMENTS:

Wilson's mine.

Described by senior writer.

Monster.

Uncle Sam.

Similar to Wilson's, and in same group on the north side of Dutch Mountain.

4. VEINS IN GRANITE:

Climax.

Success.

These mines have developed fissure veins in granite,

accompanied by displacement and shearing. The vein minerals are quartz, pyrite, galena, sphalerite, the sulphides remaining much nearer the surface than in neighboring ore-bodies in limestone.

5. DISSEMINATIONS IN GRANITE:

Rodenhouse.

This prospect shows crushed, sheared, chloritized granite, with a few specks of cupriferous pyrite.

THE SIGNIFICANCE OF CERTAIN MEXICAN OIL FIELD TEMPERATURES.

E. DEGOLYER.

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INTRODUCTION.

One of the most notable characteristics of the Mexican oil fields, aside from the enormous daily production and total productivity of some of the gushers encountered in drilling, is the great heat of the oil produced. The high temperature of the oils and of the underlying or "bottom" waters from many of the wells of the Tampico-Tuxpam region is so marked that it can hardly escape the attention of even the most casual observer.

Such natural temperatures (90°–181° F. or 32°–83° C.) are in themselves of considerable scientific interest and in these fields of comparatively heavy and viscous oils, they are of quite as great

economic importance. The viscosity of the oil varying with the temperature, the later has a direct and marked effect upon the productivity of any single well, upon the amount of oil recoverable from a given unit volume of the reservoir rock, and upon the facility with which the recovered or produced oil may be pumped through pipe-lines before cooling. At ordinary or low temperatures only a portion of the present daily production of the larger wells could be forced through the well casing under existing pressures. The high temperatures are probably only second in importance to the great porosity or cavernousness of the reservoir rock in accounting for the daily capacity and productivity of such famous wells as Dos Bocas or San Diego de la Mar No. 3, Potrero del Llano No. 4, Naranjos No. 1, Casiano No. 7, Alamo No. 2, Cerro Azul No. 4, and Pazzi No. 5.

An inspection, made several years ago, of the casing-head oil and water temperatures which had been recorded up to that time, seemed to indicate to the writer that the "bottom" water temperatures were generally higher than those of the oil and suggested the possibility of underground temperature measurements giving warning of the approach of the drill to heavy water-bearing formations. The high oil temperatures suggested also the possibility of temperature measurements indicating the approach of the drill to oil-bearing formations as has been suggested by Höefer[1] and by Koenigsberger & Mühlberg.[2]

With these possibilities in mind, the writer undertook a series of temperature measurements in various wells being drilled in the Tampico-Tuxpam region by the Mexican Eagle Oil Co., Ltd. This work was often interrupted and finally discontinued because of the pressure of other economic work and the partial suspension of drilling operations in 1914.

The results secured were not sufficient to prove or disprove the various theories which suggested themselves, but the observations made, together with numerous subsequent oil and water temperature measurements, indicate certain facts of both scien-

[1] Econ. Geol., Vol. VII., pp. 536–541, 1912, C. W. Washburne's translation.
[2] Neues Jahrb., 31, 107 (1911).

tific and economic interest. A consideration of the various observed temperatures certainly invites speculation as to the source of the heat, reasons for variation in the temperature of oils from the same well, from different wells, and from different fields, reasons for differences in oil and water temperatures and finally, as to whether or not the variations in temperature can be turned to some practical account in oil-field exploration.

Acknowledgment is due and is gratefully rendered to Messrs. H. A. Brady, Lewis C. Chapman, and Robert Goodrich for making many of the observations of rock temperature given in the present paper, to Mr. John Johnston of the Geophysical Laboratory, Carnegie Institution of Washington, for the model of thermometer and thermometer case used, to Mr. W. E. Wrather for his contribution as to temperatures in the United States, and to the writer's various colleagues in the Mexican fields for many of the oil and water temperatures. The writer is further indebted to the notes of Lord Cowdray for certain oil temperatures from Dos Bocas and Potrero del Llano, to J. B. Body, Esq., for permission to publish the present paper, and to the late Dr. C. Willard Hayes for authorization to carry on the work described, as well as for his kind interest and stimulating advices.

METHODS OF TEMPERATURE MEASUREMENTS.

The various oil and water temperatures, unless otherwise noted or unless given on authority other than that of the author, have been taken from direct-reading mercury thermometers of the type generally used in the chemical laboratory and in oil-field practice in connection with oil gauging. The procedure employed has been the insertion of such thermometer into the outcoming oil or water at the casing-head of the well for a period long enough to permit a proper observation to be made. Unfortunately, this method of observation is not always applicable as the connection between the well and the collecting tanks, which may be several miles from the well, may be so tight and the well working under such pressures that observation can only be made at the collecting tank. Temperatures generally quoted or

given by field men are most likely to be the temperatures taken at collecting tanks for gauging purposes and are almost valueless for comparison with casing-head temperatures. Some of the following oil and water temperatures as given for individual wells are doubtless as much as 10° F. different from the actual casing-head temperature, a difference due to differences in methods and points of observation, and consequently one finds it necessary to be extremely critical in making use of the various oil and water temperatures quoted.

The underground temperatures have been measured by means of straight maximum thermometers[3] with scale extending from 0°–100° C., and which could be read with a fair degree of accuracy to 0.1° C. These thermometers were used in sets of three, being protected from each other and bound together with ordinary rubber bands. They were further protected by bits of rubber tubing forced on and extending for one half to one inch beyond each end of the thermometer.

In taking the first measurements each set of three thermometers was put into a steel capsule, opening at one end by a screw cap and of proper interior dimensions for taking the thermometers. This cylinder was more tightly closed by a small steel plug and leather washer fitting into its open end and being forced down so as to make a tight joint by the screwing on of the upper or thimble end of the capsule.[4] This capsule or case was fitted with eyelets at each end for attaching it to the measuring line or "sand" line when lowering the thermometers into the borehole.

Some six cases of the type described, together with necessary thermometers and line with which to lower them into the borehole constituted the observing apparatus. This was found to be bulky, heavy and inconvenient however and subsequently the entire outfit was so reduced as to consist only of the necessary thermometers and one steel thermometer case.

The case was used only for the bottom of the boreholes, which usually contained drilling water, or, when holes were found to

[3] Instruments made by H. J. Green, 1191 Bedford Ave., Brooklyn, N. Y.
[4] This entire scheme was of the type furnished by Mr. Johnston.

be filled or partially filled with water or oil, observations were made one at a time using the case in each instance.

For observations in dry boreholes or that portion of the bore which did not contain fluid, the bare thermometers were wrapped in burlap and securely lashed to the steel cable carrying the bailer, known to drillers as the sand line.

The various points on the sand line were determined by measuring with tape that amount of the line passing from the casing-head over the crown pulley in the top of the derrick to the "sand reel" or spool upon which the sand line is reeled. This measurement having been determined, the sand line was measured off rapidly in these units and the exact points for observation on it were determined by measurement from the end of the nearest unit. Thus for observation on a single borehole, ten sets of thermometers might be inserted in it at the same time.

The author recommends the wrapping of the thermometers in burlap and lashing of them to sand lines as highly preferable for dry-hole work to other types of cases, as it was found by actual experience that the thermometers were less likely to be jarred than when in a metal case, and that they do not have to be withdrawn from the well so slowly for fear of developing frictional heat by the rubbing of the metal case against the well casing as do thermometers enclosed in metal cases.[5]

The method of depth measurement described is generally accurate to within a few feet in a very deep bore and it can be roughly checked by casing measurement. The distance between different sets of thermometers which is most important in the determination of geothermal gradients, can be kept with exactness. The measurements made in this manner are more accurate than those of the average well log.

It was found by experiment that 1½ hours was sufficient time to leave the thermometers in a well for in that time they attained temperature of the zone in which they were placed. Thermome-

[5] This frictional heat might be considerable. The sand cuttings from the metal bailer of a deep well showed a temperature of 193° F. though the maximum underground temperature read in the same well was only 181° F.

ters left 1½ hours showed the same results as when left at the same points over night.[6]

GENERAL GEOLOGIC CONDITIONS.[7]

The coastal plain of the part of northeastern Mexico including the Tampico-Tuxpam region, in which the temperature observations set forth in the present paper were taken, is made up of a thick series of Cretaceous limestones overlain by a thick series of Tertiary shales, marls, limestones, and sandstones. This entire series of sedimentary rocks has been cut and intruded by dikes, sills, laccoliths, and plugs, for the most part of volcanic rock of basalt types, and is in places covered by broad and thick lava flows.

The basal sedimentary rock, so far as we are concerned in this paper, is the very thick series of Cretaceous limestones known as the Tamasopo limestone. It is the most important, probably the parent, oil-bearing rock of the region and is the reservoir rock of the Ebano (?), Topila, Panuco, Potrero del Llano, Los Naranjos, Casiano-Tepetate, Dos Bocas, and Alamo pools. The uppermost part of this limestone is the oldest formation in which any of the underground temperatures were observed.

The uppermost limestone is often very porous or cavernous; the caverns apparently being solution cavities, their formation being aided perhaps by fault zones,[8] and extending to unde-

[6] Johnston and Adams present an excellent paper on the measurement of temperature in boreholes, ECON. GEOL., XI., pp. 741–762, 1916, describing the technique of measurement mith mercury and electrical resistance thermometers. They state that 0.1° C., the degree of precision attainable with the mercury thermometers, is insufficient to determine the reality of small differences of gradient in comparatively thin strata. The writer suggests that greater refinement is needless in the average well drilled for commercial purposes at the present time where errors of 2–3 feet are quite common and errors of 5–10 feet in depth measurement are not altogether uncommon.

[7] Further information regarding the geology of this region has been given by the author in ECON. GEOL., Vol. X., pp. 651–662, 1915, *Am. Inst. Min. Eng., Trans.*, Vol. LII., pp. 265–280, 1915.

[8] Dolomitization has been suggested as accounting for pore space in this formation. In order to decide this point, the author had samples of the oil-bearing limestone from Dos Bocas, Naranjos, Tepetate, and Potrero del

terminate depths in the series. This condition is well shown in outcrops of the Tamasopo and is particularly well marked by the occurrence of enormous caverns, sinks, springs and even the debouching of underground rivers, such as the Rio Coy and Rio Choy, along the line of contact between the limestone and the overlying and more impervious San Felipe beds.

This cavernous condition of the limestone and the manner of oil occurrence is of considerable importance in accounting for the difference in ranges of oil temperatures from those of the underlying waters. In the author's opinion, the floor of the oil body is not generally marked by an impervious underlying formation, as is so often the case when the reservoir rock is a sandstone of comparative thinness, but is determined by the plane of contact formed with underlying salt water. The heat of the oil would seem to be largely derived from the underlying water.

The Tamasopo limestone is overlain unconformably (?) by some 400–800′ of alternating, thin-bedded, argillaceous limestones and shales known as the San Felipe beds. This formation is of lower Eocene or Eocene-Cretaceous age and is often oil bearing.

The San Felipe formation grades imperceptibly into an overlying series of blue shales with occasional thin sandstones and limestones known as the Mendez shale. This formation is of Eocene age, has a thickness of 2000′–4000′ and is not generally oil bearing.

The Mendez shale is overlain by various series of shale, sandstone, and limestones, known locally as the Temepache, Comcar, San Pedro, and San Fernando formations, all believed to be of Oligocene age.

The igneous rocks of the region consist of basalts and allied types such as dolerites, diabase, and gabbros with volcanic breccias, agglomerates, and ash. Metamorphism of the contiguous sedimentary rocks, both by heat and brecciation, has accompanied

Llano analyzed. The analyses, made by E. S. Porter, showed only insignificant amounts of magnesium, equivalent in the maximum case to 0.96 per cent. $MgCO_3$.

the various intrusions. While not contemporaneous, the various intrusions and flows apparently belong to the same epoch, an epoch of which Popocatapetl, which has been active within the last two centuries, probably represents a dying remnant. The entire series of sedimentary rocks including upper and lower Oligocene formations has been intruded by dikes, sills and plugs and covered by lava flows in various localities.

The two areas of greatest igneous activity consist of an area in southern Tamaulipas, comprising the southern part of the Sierra Tamaulipas, and extending from Aldama to San Jose de las Rusias and an area in eastern Puebla and northern Vera Cruz consisting of an extension of the igneous area of the central plateau of Mexico into the coastal plain and roughly limited by the coast line and a line through the towns of Huejutla, Hdg., and Ozuluama, V. C.

The observed oil, water, and underground temperatures as given in this paper have been arranged in three groups with regard to their geographic relation to these areas of igneous activity. The San Pedro group includes temperatures observed in an area showing almost no evidences of igneous activity, the only outcrop of igneous rock in the region being a small diorite plug near Tancanhuitz, S. L. P. The Panuco River group includes temperatures observed in an area of slight igneous activity, the only known evidences consisting of several small volcanic plugs near Ebano, Atascador, and Los Esteros, the big plug Pico de Bernal near Magiscatzin, Tamps., an old lava flow or denuded sill some 9–10 miles south and slightly west of Panuco, and the Tampalache dike or sill in the northern part of the Panuco field. The Tuxpam group includes the temperatures from a region of very considerable igneous activity. The San Jose las Rusias and Furbero temperatures, which are not included in the groups, are also from areas of considerable igneous activity.

OBSERVED TEMPERATURES.

The oil and water temperatures are given in the Fahrenheit scale since such additional information as may in future be

OIL TEMPERATURES.

Well.	Depth, Feet.	Maximum.	Minimum.	Latest.	Remarks.
San Pedro Group:					
San Pedro No. 1	4,000	90° F.	80° F.	90° F.	Small well.
La Labor No. 1	4,043	139° F.			Small well, in stratum.
Panuco River Group:					
Ebano field				105° F.	By I. C. White.
Panuco field:					
Pazzi No. 5	1,805	117° F.	89° F.		37,000 bbl. well.
Barbarena No. 1	1,755			101° F.	1,000 bbl. well.
Zuniga No. 1	2,270			101° F.	1,000 bbl. well.
Cicero No. 2	2,015	106° F.	101° F.		20,000 bbl. well.
Tal Vez No. 1	2,114			84° F.	When producing 200 bbl.
Harmon Well	2,120	116.8° F.			50,000 bbl. well, in stratum.
Topila field:					
Sante Fe No. 5	2,390			110° F.	Local report.
Tuxpam Group:					
Casiano field:					
Casiano No. 7	2,112	124° F.	110° F.		I. C. White and local report.
Naranjos field:					
Naranjos No. 1	1,885	145.4° F.			Big well, in stratum.
Cerro Azul field:					
Cerro Azul No. 4	1,752	133° F.	122° F.		Big well, I. C. White and local report.
Potrero del Llano field:					
Potrero Nos. 1 and 2		114° F.	102° F.		Small wells.
Potrero No. 4	1,911	149° F.	102° F.		100,000 bbl. well.
Potrero No. 3	1,964	152.8° F.			Stagnant oil in stratum.
Alazan No. 4	2,001	128° F.	65° F.		
Alazan No. 6	2,080	128° F.	119° F.		
Alazan No. 8	2,292	145.4° F.	118° F.		Maximum, in stratum.
Alazan No. 9	2,077	125° F.	118° F.		
Tanhuijo field		91° F.	70° F.		Small shallow wells.
San Marcos field:					
San Marcos No. 1	3,317	85° F.	70° F.		Small well.
San Marcos No. 2	1,327	85° F.	65° F.		Small well.

Well	Depth, Feet.	Maximum.	Minimum.	Latest.	Remarks.
Tierra Amarilla field:					
Various wells		110° F.	80° F.		Small wells.
Tierra Amarilla No. 6	2,442	138° F.			Big well.
Tumbadero No. 1	2,961	117° F.			
San Diego de la Mar field:					
San Diego No. 3	1,824	157° F.	133° F.		By C. F. de Ganahl.
Furbero field:					
Furbero No. 6	1,650	115.7° F.			In stratum.
Furbero No. 25	2,650	122° F.			In stratum.

SALT-WATER TEMPERATURES.

San Pedro Group:					
Palmira No. 1	1,400	92° F.			Well flowing 2,000 bbls.
Panuco River Group:					
Ebano field					No report.
Panuco field					No report.
Topila field					
Sante Fe No. 5	2,390	130° F.			Local report.
Tuxpam group:					
San Diego No. 2	2,007	132° F.			Leaking 50 to 100 bbls.
San Diego No. 3 (Dos Bocas)	1,824	165/170° F.			Flowing continuously.
San Miguel No. 1	2,700	148° F.			Salt water well.
Golfo No. 1	2,613	162° F.			Flowing continuously.
Tumbadero No. 1	2,979	81° F.			Report of doubtful value.
Tumbadero No. 2	2,970	180° F.			Report of doubtful value.
Llano Grande No. 1	2,730	149° F.			Taken in stratum.
Tierra Amarilla field:					
Tierra Amarilla No. 1	2,490	120/140° F.			Small flow water.
Tierra Amarilla No. 6	2,442	148° F.			As well went to water.
Tierra Amarilla No. 10	2,538	158° F.			Taken in stratum.
Tierra Amarilla No. 14	2,580	165° F.			Constant heavy flow.
Alazan No. 3	2,530	148° F.			Constant flow.
Alazan No. 3	2,530	98° F.			Choked to 140 bbls.
Furbero No. 9	2,333	123° F.			Taken in stratum.
San Jose de las Rusias		160° F. plus			Report.

UNDERGROUND TEMPERATURES.

San Pedro Group.

La Labor Well No. 1.

Observation.		Total Depth.[9]	Gradient.[10]		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.				Regional mean temperature.[11]
			63.5′	34.8 m.	
3,635′ = 1,107.8 m...	56° C. = 132.8° F.	4,043′ = 1,232.3 m.			Oil.
			0	0	Deadened by oil?
3,735′ = 1,138.3 m...	56° C. = 132.8° F.	4,043′ = 1,232.3 m.			Oil.
			37.0′	20.3 m.	
3,835′ = 1,168.8 m...	57.5° C. = 135.5° F.	4,043′ = 1,232.3 m.			Oil.

Note.—No drilling had been carried on for thirteen days, no water in well which was full of oil but not flowing.

Barrancon Well No. 1.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.				Regional mean temperature.
			58.9′	32.3 m.	
3,268′ = 996.1 m...	55° C. = 131° F.	4,068′ = 1,240 m.			
			55.5′	30.4 m.	
3,368′ = 1,026.5 m...	56° C. = 132.8° F.	4,068′ = 1,240 m.			
			55.5′	30.5 m.	
3,468′ = 1,057 m....	57° C. = 134.6° F.	4,068′ = 1,240 m.			
			55.5′	30.5 m.	
3,568′ = 1,087.5 m...	58° C. = 136.4° F.	4,068′ = 1,240 m.			
			51.1′	28 m.	
3,660′ = 1,115.5 m...	59° C. = 138.2° F.	4,068′ = 1,240 m.			
			22.2′	12.2 m.	
3,760′ = 1,145 m....	61.5° C. = 142.7° F.	4,068′ = 1,240 m.			Local heat?
			0	0	
3,860′ = 1,176.5 m...	61.5° C. = 142.7° F.	4,068′ = 1,240 m.			
			55.5′	30.5 m.	
3,960′ = 1,207 m....	62.5° C. = 144.5° F.	4,068′ = 1,240 m.			
			9.2′	5.1 m.	Valueless.
4,060′ = 1,237.5 m...	68.5° C. = 155.3° F.	4,068′ = 1,240 m.			Drilling heat.
			3.5′	1.9 m.	
4,076′ = 1,242.4 m...	71° C. = 159.8° F.	4,079′ = 1,243 m.			Drilling heat.

[9] Depth of well at time observation was made.

[10] Geothermal gradient under *A* stated in feet per degree Fahrenheit and under *B* stated in meters per degree Centigrade.

[11] The only available statement of mean temperature for this region is that of 24.2° C. for Tampico as determined by Dr. Antonio Matienzo, of the Hospital Militar, for the years 1905 and 1906. Several observations showed 24° to 24.5° C. to be the temperature of the soil at depths of 5′–10′.

Note.—Drilling suspended in order to take temperature. The 4,060′ observation shows the frictional heat of drilling. The hole contained a small amount of drilling water but no oil or gas. The apparently abnormal temperature at 3,760′ is probably due to some local source of heat, such as oxidation of iron pyrites. Neglecting this observation we have a more normal *A* gradient 44.4′ between 3,660′ and 3,860′.

San Ciro Well No. 1.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.				Regional mean temperature.
			52.3′	28.7 m.	
2,995′ = 912.8 m....	56° C. = 132.8° F.	2,995′ = 912.8			Drilling heat.

Note.—Drilling was suspended in this well for the purpose of taking temperatures. As a consequence the observed temperature is apparently too high. This well is near Barrancon Well No. 1, was drilled under the same conditions, and has a very similar log but the observed temperature corresponds to the normal temperature for a point almost four hundred feet deeper as observed in the Barrancon well.

PANUCO RIVER GROUP.[12]

Topila Field, Mexican Oil Co. No. 3.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.	?			
			59.3′	32.5 m.	
2,270′ = 691.9 m..	45.5° C. = 113.9° F.	?			Oil struck at 2,280′.

Panuco Field, B. P. Co. Chotes No. 1.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.				
			45.3′	24.8 m.	
1,775′ = 541 m...	46° C. = 114.8° F.	1,795′ = 547.1 m.			Dry hole.
			11.3′	6.3 m.	Abnormal, oil heat.
1,800′ = 548.6 m.	47.2° C. = 117° F.	1,840′ = 560.8 m.			Oil not flowing.
			−75′	−42.8 m.	
2,025′ = 617.2 m.	45.6° C. = 114° F.	2,065′ = 629.4 m.			Oil and gas.
			−3.2′	− 1.7 m.	
2,034′ = 619.9 m.	44° C. = 111.2° F.	2,074′ = 632.1 m.			Just after flow of oil.

Note.—The last two temperatures were taken under conditions almost ideal to allow adiabatic cooling by gas expansion and are valueless for purpose of determining geothermal gradient.

[12] Underground temperatures in this group by courtesy of J. M. Muir.

TUXPAM GROUP.

Naranjos Field, Naranjos Well No. 1.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.				Regional mean temperature.
1,800′ = 548.6 m.	63° C. = 145.4° F.	1,895′ = 577.5 m.	25.7′	14.1 m.	Well flowing oil.

Note.—Manifestly, this single temperature is valuable only as an oil temperature.

Naranjos Field, Naranjos Well No. 2.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.				Regional mean temperature.
1,900′ = 579.1 m.	56° C. = 132.8° F.	1,946′ = 593.1 m.	33.2′	18.2 m.	No oil.

Tanhuijo Field, Tanhuijo Well No. 3.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.				Regional mean temperature.
1,060′ = 323 m. .	38° C. = 100.4° F.	3,190′ = 972.3 m.	42.7′	23.4 m.	
1,660′ = 505.9 m.	45° C. = 113° F.	3,190′ = 972.3 m.	47.6′	26.1 m.	
2,260′ = 688.8 m.	53.5° C. = 128.3° F.	3,190′ = 972.3 m.	39.2′	21.5 m.	
2,560′ = 780.2 m.	56.5° C. = 133.7° F.	3,190′ = 972.3 m.	55.5′	30.4 m.	
2,860′ = 871.7 m.	62.2° C. = 143.9° F.	3,190′ = 972.3 m.	29.4′	16.0 m.	
3,160′ = 963.14 m.	71.3° C. = 160.1° F.	3,190′ = 972.3 m.	18.5′	10.0 m.	Drilling heat.
3,500′ = 1,066.8 m.	83° C. = 181.4° F.		15.9′	8.86 m.	Drilling heat?

Note.—This well had encountered numerous shows of oil and gas throughout its entire depth. Had just been thoroughly washed and allowed to stand twelve hours before temperatures were taken. Salt water was encountered at 3,538′.

Tanhuijo Field, Tanhuijo Well No. 11.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.				Regional mean temperature.
			50.6′	27.7 m.	
1,500′ = 457.19 m.	40.7° C. = 105.2° F.	1,500′ = 457 m.			1,300′ of oil in hole.

Tanhuijo Field, Tanhuijo Well No. 19.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.	?			Regional mean temperature.
			20.5′	11.2 m.	
325′ = 99 m...	33° C. = 91.4° F.	?			Drilling heat.
			486.1′	266.7 m.	Deadened by water?
1,200′ = 365.7 m.	34° C. = 93.2° F.	?			Well full of drilling water.

Note.—The manifestly abnormal temperature at 325′ destroys the value of both gradients. Ignoring it, we have gradients of 68.1′ and 37.3 meters.

Tanhuijo Region, San Marcos Well No. 4.

Observation.		Total Depth.	Gradie t.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.	?			Regional mean temperature.
			41.5′	22.7 m.	
2,940′ = 895.1 m.	63.5° C. = 146.3° F.	?			Oil temperature.
			0	0	
3,200′ = 975.3 m.	63.5° C. = 146.3° F.				Oil temperature.

Note.—Gradient of no value, oil temperature only.

Tanhuijo Region, Tierra Blanca Well No. 2.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.	?			Regional mean temperature.
			50.0′	27.4 m.	
2,500′ = 761.98 m.	52° C. = 125.6° F.	?			Oil at 1,700′.
			61.1′	33.52 m.	
2,610′ = 795.5 m.	53° C. = 127.4° F.	?			

Tierra Amarilla Field, Well No. 9.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.				Regional mean temperature.
2,370′ = 722.3 m.	65° C. = 149° F.		32.2′	17.7 m.	Oil.

Tierra Amarilla Field, Tierra Amarilla Well No. 10.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.	?			Regional mean temperature.
170′ = 51.8 m.	39° C. = 102.2° F.	?	6.39′	3.5 m.	Drilling heat.
900′ = 274.3 m.	41° C. = 105.6° F.	?	214.7′	111.2 m.	
2,447′ = 745.8 m.	70° C. = 158° F.	?	29.5′	16.2 m.	Hole full salt water.

Note.—The observation at 170′ is abnormal. Disregarding it we have gradients of 30′ and 16.2 m. to 900′. The last observation is of value only as a water temperature.

Potrero del Llano Field, Potrero Well No. 3.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.	?			Regional mean temperature.
1,950′ = 594.3 m.	67.3° C. = 153.1° F.	?	25.2′	13.8 m.	

Note.—This observation was made February 9, 1913, when the well was full of oil and some drilling water, and had stood a long time. The temperature of 67.3° C. or 153.1° F. is much greater than any oil, water, or earth temperature observed in this immediate region and, in the author's opinion, is due to heat caused by the oxidation of iron pyrites, which are known to be of common occurrence in the strata near the point where the observation was made.

Potrero del Llano Field, Potrero Well No. 5.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.				Regional mean temperature.
840′ = 256 m....	45.5° C. = 113.9° F.	840′ = 256 m.	21.9′	12.01 m.	Chemical heat?

Note.—This temperature was taken under conditions similar to those in Potrero Well No. 3.

Potrero del Llano Field, Alazan Well No. 6.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.	?			Regional mean temperature.
1,600′ = 487.6 m.	53° C. = 127.4° F.	?	30.8′	16.9 m.	Closed some time, oil, lots of gas.
2,034′ = 619.9 m.	67° C. = 152.6° F.	?	17.2′	9.45 m.	Drilling heat?

Note.—Both observations are abnormal. The 1,600′ observation was made after drilling had been suspended some time and is probably higher than the true temperature of the stratum because of heat resulting from the oxidation of iron pyrites. The second temperature, taken after drilling had been resumed, shows drilling heat. Oil was encountered at 2,080′.

Potrero del Llano Field, Alazan Well No. 7.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.				Mean regional temperature.
1,985′ = 605 m...	62° C. = 143.6° F.	1,985′ = 605 m.	29.2′	16.0 m.	Well full of drilling water.

Note.—This temperature is also abnormally high. It was taken under conditions similar to those in Potrero wells Nos. 3 and 5 and Alazan well No. 6, and has probably been affected by similar influences.

Potrero del Llano Field, Alazan Well No. 8.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.	2,164′ =659.5 m.			Regional mean temperature.
			29.8′	16.4 m.	
1,064′ =324.3 m.	44° C. =111.2° F.	2,164′ =659.5 m.			
			48.78′	26.4 m.	
1,264′ =385.2 m.	46.3° C. =115.3° F.	2,164′ =659.5 m.			
			50.0′	27.7 m.	
1,464′ =446.2 m.	48.5° C. =119.3° F.	2,164′ =659.5 m.			
			80.0′	43.5 m.	
1,664′ =507.1 m.	49.9° C. =121.8° F.	2,164′ =659.5 m.			Low?
			35.7′	19.6 m.	
1,864′ =568.1 m.	53° C. =127.4° F.	2,164′ =659.5 m.			
			23.8′	13.8 m.	
1,964′ =598.6 m.	55.2° C. =131.6° F.	2,164′ =659.5 m.			
			33.3′	16.9 m.	
2,064′ =629.0 m.	57° C. =134.6° F.	2,164′ =659.5 m.			
			11.1′	6.1 m.	
2,164′ =659.5 m.	62° C. =143.6° F.	2,164′ =659.5 m.			Drilling heat.
1,780′ =542.5 m.	63° C. =145.4° F.	?	——	——	After oil encountered.

Note.—During the observations except the last (1,780′) the well was making a small amount of gas but no oil. The last observation is of value only as an oil temperature, as it was made after oil in quantity had been encountered and the well had made a flow. Thermometers held just in the mouth of the well casing while the well was gassing showed a temperature of 73.5° F., the air temperature at the time being 77° F. This lower temperature was the result of adiabatic expansion and shows one of the influences to which all oil region temperatures may be subjected.

Potrero del Llano Field, Alazan Well No. 9.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.				Regional mean temperature.
			35.6′	19.5 m.	
1,140′ =347.4 m.	42° C. =107.6° F.	?			
			20.7′	11.3 m.	
1,700′ =518.1 m.	57° C. =134.6° F.	1,700′ =518.1 m.			Oil show at 1,720′.
			13.3′	7.3 m.	
2,012′ =613.2 m.	70° C. =158° F.	2,112′ =643.6 m.			No drilling heat.
			0.93′	0.5 m.	
2,017′ =614.7 m.	73° C. =163.4° F.	2,117′ =645.1 m.			After drilling one hour.

Note.—The last two observations show the effect of the friction of drilling in generating heat. From such observations as the author has made, 72°–73° C. seems to be a very common temperature in strata where drilling is going on.

Llano Grande Well No. 1.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.				Regional mean temperature.
			62.5′	33.8 m.	
200′ = 60.95 m.	26° C. = 78.8° F.	450′ = 137.1 m.			
			35.7′	19 m.	
300′ = 91.43 m.	27.6° C. = 81.6° F.	450′ = 137.1 m.			
			22.7′	12.7 m.	
400′ = 121.92 m.	30° C. = 86° F.	450′ = 137.1 m.			Drilling heat?
			29.3′	16.1 m.	
2,620′ = 798.55 m.	72° C. = 161.6° F.				Drilling heat.
			−5.0′	−2.7 m.	
2,683′ = 817.75 m.	65° C. = 149° F.	2,730′ = 832 m.			Flowing salt water.

Note.—Apparently the 400′ temperature was effected by the heat of drilling. The 2,620′ temperature was certainly so effected. The last temperature is of value merely as a water temperature.

Tlacolula Well No. 1.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
75′ = 22.8 m. . .	23.3° C. = 73.9° F.	2,595′ = 790.9 m.			
			33.4′	18.3 m.	
600′ = 182.8 m. .	32.0° C. = 89.6° F.	2,595′ = 790.9 m.			
			39.7′	21.7 m.	
1,200′ = 365.7 m. .	40.4° C. = 104.7° F.	2,595′ = 790.9 m.			Oil and gas 1,140′–1,185′.
			106.5′	58.2 m.	
1,850′ = 563.8 m. .	43.8° C. = 110.8° F.	2,595′ = 790.9 m.			
			−6.3′	−3.46 m.	
1,950′ = 594.3 m. .	35° C. = 95° F.	2,595′ = 790.9 m.			Adiabatic expansion?
			3.96′	2.17 m.	
2,050′ = 624.8 m. .	49° C. = 120.2° F.	2,595′ = 790.9 m.			
			15.8′	8.7 m.	
2,250′ = 685.7 m. .	56.0° C. = 132.8° F.	2,595′ = 790.9 m.			Igneous rock?
			−3.47′	−1.9 m.	
2,350′ = 716.2 m. .	40° C. = 104° F.	2,595′ = 790.9 m.			Adiabatic expansion?
			14.7′	8.02 m.	
2,450′ = 746.7 m. .	43.8° C. = 110.8° F.	2,595′ = 790.9 m.			
			4.54′	2.5 m.	
2,550′ = 777.2 m. .	56° C. = 132.8° F.	2,595′ = 790.9 m.			Oil show 2,500′–2,520′.
			34.5′	18.9 m.	
3,545′ = 1,080.5 m.	72° C. = 161.6° F.				Drilling heat?
			—	—	
3,580′ = 1,091.1 m.	72° C. = 161.6° F.				Drilling heat?
			—	—	
3,710′ = 1,130.7 m.	72° C. = 161.6° F.				Drilling heat?
			175.5′	96.4 m.	
4,026′ = 1,227.1 m.	73° C. = 163.4° F.	4,126′ = 1,257.5 m.			Oil and gas shows.

Note.—The well is in a region of intense late Oligocene or post-Oligocene intrusion, in fact, some volcanic rocks were encountered in drilling. It is within 1,000 meters of an immense dyke or plug.

Tlacolula Well No. 2.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.				Regional mean temperature.
			15.0′	8.1 m.	
75′ = 22.8 m. . .	27° C. = 80.6° F.	2,605′ = 794 m.			
			26.8′	14.6 m.	
475′ = 144.7 m. .	35.3° C. = 95.5° F.	2,605′ = 794 m.			
			102.0′	56.44 m.	
975′ = 297.1 m. .	38° C. = 100.4° F.	2,605′ = 794 m.			
			49.5′	27.2 m.	
1,475′ = 449.5 m. .	43.6° C. = 110.5° F.	2,605′ = 794 m.			
			43.4′	23.8 m.	
1,975′ = 601.95 m.	50.0° C. = 122.0° F.	2,605′ = 794 m.			
			50.0′	27.7 m.	
2,075′ = 632.44 m.	51.1° C. = 124° F.	2,605′ = 794 m.			
			29.4′	16.03 m.	
2,175′ = 662.9 m. .	53° C. = 127.4° F.	2,605′ = 794 m.			
			55.5′	30.5 m.	
2,275′ = 693.4 m. .	54° C. = 129.2° F.	2,605′ = 794 m.			
			55.5′	30.4 m.	
2,375′ = 723.8 m. .	55° C. = 131° F.	2,605′ = 794 m.			
			100.0′	50.8 m.	
2,475′ = 754.3 m. .	55.6° C. = 132° F.	2,605′ = 794 m.			
			12.0′	6.63 m.	
2,575′ = 784.8 m. .	60.2° C. = 140.3° F.	2,605′ = 794 m.			In oil?
			31.4′	17.2 m.	
3,810′ = 1,161.2 m.	82° C. = 179.6° F.				Drilling?
			−10.7′	−5.9 m.	
3,868′ = 1,178.9 m.	79° C. = 174.2° F.				Drilling?
			11.3′	6.25 m.	
3,950′ = 1,203.9 m.	83° C. = 181.4° F.				Drilling?
			−12.0′	−6.6 m.	
4,080′ = 1,243.5 m.	77° C. = 170.6° F.				2,000′ drilling water in hole.

Note.—This well is also in a region of intense volcanic activity of late Oligocene or post-Oligocene (to recent?) date. The well was making some gas when observations were made.

Tlacolula Well No. 3.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.				
			53.5′	29.3 m.	
1,520′ = 463.3 m. .	40° C. = 104.0° F.				
			30.1′	16.5 m.	
2,145′ = 653.7 m. .	51.5° C. = 124.7° F.				Oil show at 2,130′.

Note.—This well is also in an old volcanic region.

Furbero Well No. 6.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.				Regional mean temperature.
			41.1′	22.5 m.	
1,650′ = 502.9 m.	46.5° C. = 115.7° F.				Well full of oil and flowing.

Note.—Observations by Dr. Max Mühlberg with instruments and under conditions not known to author. Log shows metamorphosed shale at 1,650′.

Furbero Well No. 9.

Observation.		Total Depth.	Gradient.		Remarks.
Depth.	Temperature.		*A.*	*B.*	
Surface.....	24.2° C. = 75.6° F.				Regional mean temperature.
			48.1′	26.3 m.	
2,276′ = 693.7 m.	50.5° C. = 122.9° F.				Salt water in well.

Note.—Observations by Dr. Max Mühlberg with instruments and under conditions not known to author. Log shows metamorphosed shale at 2,276′ and 41′ lower, the top of the Furbero laccolith is encountered.[13]

secured, as well as such information as is available for comparative purposes, is likely to be given in that scale. Underground temperatures are given in both Centigrade and Fahrenheit. The temperatures are given as maximum, minimum, and latest. This refers only to the maximum, minimum and latest observed or reported observations and does not indicate the full extent of the actual range in temperature which may have occurred. In fact, since the minimum temperatures have a tendency to approach, with considerable lag, the mean atmospheric temperature of the region, as the rate of production of a flowing well is choked to approach zero, such temperatures have little value for comparative purposes and are often so casual as to be altogether valueless.

Comparative Data from Other Countries.

Much of the available data regarding subterranean temperatures is the result of observations made in boreholes in oil regions,

[13] Description of this occurrence of oil in metamorphosed shale and igneous rock is given in *Trans. Am. Inst. Min. Engrs.*, Vol. 52, 1915, pp. 267–280.

but almost no information of comparative value is available regarding the temperature of the oils and oil-field waters themselves. Koenigsberger and Mühlberg,[14] Höfer,[15] and Lindgren[16] present summaries of subterranean temperatures; the first two papers being of especial value in this connection because they concern themselves with oil-field conditions and the summary by Lindgren being of particular value because the temperatures are arranged in groups according to the various factors which control their variation from the supposed normal.

As to oil and water temperatures, A. Beeby Thompson[17] notes that the temperature of oils in the Baku field is 75°–95° F. He notes two unusual sulphurous water temperatures of 104° F. and 117.5° F. in the Grosny field, and concludes that they must have been due to some chemical action connected with the presence of sulphur for other waters not far away, from equal or greater depths exhibit neither such high temperatures nor such character.

E. H. Pascoe[18] notes temperatures of up to 86° F. in flowing oils at Yenangyaung, Burma, where the surface temperature was 76°–78° F. and notes a temperature of 148° F. at a point 3½ feet below the surface on a recent island apparently formed by a mud volcano. He further notes hot springs with temperatures of 89°–130° F. in the oil regions of Assam.

In the United States, where almost two thirds of the world's petroleum has been and is being produced and where oil-field operations have been conducted on a commensurate scale, there is little enough information as to subterranean temperatures and almost no recorded information as to oil and oil field water temperatures.[19] The only oil-field temperatures which seem to

[14] *Op. cit.*

[15] *Op. cit.*

[16] "Mineral Deposits," pp. 77–81, 1913.

[17] "Oil Fields of Russia," pp. 103, 268, 269 (the revised second edition), London, 1908.

[18] *Memoirs Geol. Surv. of India*, Vol. XL., Calcutta, 1912.

[19] In order to ascertain what information might be available regarding oil and water temperatures, the author circularized the state geologists of the oil-producing states in the United States. Replies were received to all of the queries but one and the result was the same in each instance, namely, the statement that there was no information on this subject.

have attracted any attention are those from the saline dome region of southern Texas and Louisiana. Most writers describing this region have noted high temperatures for both oils and waters.[20] Kennedy[21] notes that:

> The temperature of the water issuing from the opening at Sulphur Mine is about 100° F. and at Vinton 100° F. At Spindletop these waters ranged from 99° F. to 120° F. and at Bryan Heights 160° F. It may be noted, however, that many of the other mounds throughout the coast country produced water ranging from 116° F. at Batson to 180° F. at Saratoga.

The author is indebted to W. E. Wrather for the following information on temperatures in the Gulf Coastal region:[22]

> It has been my observation that 90° F. is probably the average normal temperature in the coastal fields of Texas and Louisiana. A rapid increase in temperature of 10°–20° F. or even more, is nearly always noted just before water makes its appearance in flowing wells. In the deep sand wells at Humble (ranging from 2,600 to 3,200 feet in depth) the temperature of wells operated on air, or flowing and making some water, will run as high as 110° F. I have noted in several instances that pumping wells making some water and roily oil, show temperatures as low as 80° F. An interesting well in the south end of the Humble field flowed 250 barrels of oil with no water, from a sand at 3,240 feet which is several hundred feet deeper than other wells in the vicinity. This oil yielded over 20 per cent. gasolene and its initial gravity was about 39° Bé.; the temperature was below 80° F. or decidedly subnormal. The gravity of oil from adjacent wells was 26° to 28° Bé. and the yield of gasolene from 4 to 8 per cent. (Temperature not given but presumably normal or higher.—Author.) The salt water in the deep sands around Humble ranges from 100°–120° F. and is not a particularly strong brine. It is not hard on casing or tubing.
>
> Temperatures at Saratoga are higher than is usual in the coastal fields. Oil from wells making no water ranges as high as 110° F. On the margin of the pool, the black sulphur and salt water in the deeper sands (1,000 to 2,000 feet) has run as high as 180° F. This is the highest temperature I have ever known in the Coast country.
>
> At Batson, Markham, Sour Lake, Anse la Butte and elsewhere, I could cite numerous instances of increase in temperature from about

[20] U. S. Geological Survey: Bulletin 212, pp. 60, 122, 1903; Bulletin 282, pp. 47, 56, 62, 66, 100, 113, 120, 1906; also Bulletin 429, 1910.

[21] Bulletin Southwest Assn. Pet. Geol., Vol. 1, p. 47, 1917.

[22] Personal communication to the author.

90° F. to 105°–114° F. just preceding the influx of water. I have often wondered what caused this phenomenon, but have about reached the conclusion that the water in the sands flanking the salt dome fields is about 20° F. higher temperature, on the average, than the oil and it seems plausible that the rapid increase in temperature is due to the fact that the oil just ahead of the water has been in most direct contact with the hot water.[23]

SIGNIFICANCE OF TEMPERATURES.

Since high temperatures are not confined to the oils and waters alone but have also been noted in boreholes where no oil or gas was present, the general tendency has been to attempt to explain them as a result of the normal increase of heat with depth. Harris[24] offers such explanation for the Gulf Coastal fields of the United States.

The normal geothermal gradient is generally given as 1° C. for every 30 m. or 1° F. for every 54.6′ of added depth. This figure is widely accepted though Bancroft[25] notes that so far as actual observations are concerned, there are far more exceptions than confirmations of this figure and Chamberlin and Salisbury[26] state that, discarding observations known to have been affected by various abnormal causes such as dying vulcanity, there is such great variation in observed temperatures that the highest geothermal gradient is more than six times as great as the lowest observed gradient.

Accepting the gradient given for comparative purposes, however, as the normal one, we find, after making allowances for local sources of heat, that the subterranean temperatures observed in the San Pedro region agree with it fairly closely. In fact, the observed gradient in Barrancon Well No. 1, to a depth of 3,660′ varies only by an insignificant fraction. We find that the observed temperatures are generally higher and the geothermal gradients are lower in the Panuco River region and the

[23] It is interesting to note that, without being aware of the author's conclusions with regard to Mexico, Mr. Wrather had reached the same conclusion as to Texas.

[24] Bull. U. S. G. S., No. 429, p. 8, 1910.

[25] *Trans. Amer. Inst. Min. Engineers*, Vol. XXXVIII., p. 263, 1908.

[26] "Geology," Vol. I., Processes and their Results, pp. 559–574, 1905.

Tuxpam region, however, than those of the normal and can only conclude that this is because these regions are subjected to heat-producing influences which are not effective in the San Pedro region.

In view of the almost total absence of volcanic rocks in the San Pedro region and their common occurrence in the other areas under consideration, and in view of evidence as to the comparative recentness of the epoch of vulcanity, the latent heat of volcanic activity suggests itself most strongly as the source of heat. This theory is further supported by the fact that the San Pedro region, the region of lowest temperatures and most normal gradients, is the region apparently least subjected to volcanic activity; the Tuxpam region, the Furbero area, and the San Jose de las Rusias area, the regions of highest temperatures and lowest gradients, have been subjected to greatest volcanic activity; and the Panuco River region, the region of intermediate temperatures and intermediate gradients, has been subjected to more igneous activity than has the San Pedro region and to appreciably less igneous activity than have the Tuxpam region and the Furbero or San Jose de las Rusias areas.

The temperatures in strata in the regions of volcanic activity, even when barren of oil and water, are higher than normal thus indicating that the strata themselves are heat conductors. The temperatures of the oil and water however, as well as the temperatures of oil- and water-bearing strata, are so much higher than those of dry strata at equal depths that they suggest not only that the fluids and saturated strata are better conductors than the comparatively dry strata, but that convection is of considerable importance in accounting for high temperatures. The Tamasopo limestone, the formation usually containing oil or water, is often so cavernous that it would permit fairly free circulation of both oil and water and it is the author's opinion that the marked difference in the range of the oil temperatures (70°–149° F.) from those of the water temperatures (92°–170° F.) is due largely to convection.

The water temperatures are apparently derived from direct

contact with the igneous rocks and this heat is transmitted by conduction and by convection to some distance from its original source whereas the heat of the oil, with its more limited occurrence, is largely derived from contact with the water and convection is of little importance.

Some of the heat, as has already been noted, is due doubtless to various chemical reactions such as the oxidation of pyrites of iron. Other writers have noted petroleum and coals as being also sources of heat. The author is of the opinion that the heat of the saline domes of the Gulf Coastal plain of the United States may be due, in part at least, to chemical reactions. Kennedy[27] notes the occurrence of free sulphuric acid in various domes and sulphur is of common occurrence in most of them.

Differences in temperature of oils and waters from different fields is due perhaps, in a great measure, to underground conditions which we cannot determine, such as varying porosity of containing strata and consequent differences in underground circulation but many of the differences are more apparent than real and are the result of the same influences which cause variation in temperature from time to time in the production of an individual well.

The most important factors causing differences in temperature between oil from different wells in the same field or in the temperature of oil or water at different times from a single individual well are loss of heat by radiation and adiabatic expansion.

Loss of heat by radiation becomes more marked as the amount of liquid produced by a well in a unit of time approaches zero. An excellent example of this is the great Potrero del Llano well. After this well had been flowing at its full capacity of more than 100,000 barrels per day for many days, the temperature of the oil was 149° F. When the well was afterward shut in, the temperature varied from 102° F. when the well was allowed to produce only a few hundred barrels per day to 133° F., when it was allowed to produce some 30,000 barrels per day. Likewise,

[27] *Op. cit.*, p. 48.

the temperature of salt water produced by Alazan well No. 3 varied from 98° F. when the well was producing at the rate of 140 barrels per day to 148° F. when the well was producing thousands of barrels per day.

While this loss of heat by radiation is of course proportional to the specific heat and conductivity of the formation through which the well passes, such factors are of little direct importance as compared with speed of production. In wells producing less than 100 barrels per day it often requires more than twenty-four hours for the fluid to pass from the bottom to the top of the well, while the same passage would be made in a few minutes in a well producing at the rate of 50,000 barrels per day. It is evident that if a well is absolutely closed for a long period and is then allowed to produce a very small amount per day, the temperature of the product will approach the mean atmospheric temperature of the region, all of the heat being lost by radiation.

The quantitative importance of the loss of heat as a result of adiabatic expansion of gases is not easily determined. It affects only the oils and gases. In most of the producing wells of the Mexican fields, large amounts of gas are present under considerable pressures and in part perhaps in solution. The Quebracha and Loma del Poza wells of the Topila region produce little oil and very large quantities of gas. The loss of heat through gas expansion at these wells has resulted in covering the casing head of the wells with frost and ice and the wells are reported to have ejected frozen chunks of oil when flowing wide open.[28]

The greatest importance of the heat from an economic standpoint is that it decreases the viscosity of the oil and permits it to flow freely. Since viscosity retards the movement of oil in the containing formation, it is of very great importance as a factor determining the rate of production per day.[29] Some idea of the effect of heat in reducing viscosity may be obtained from the following table of viscosities of a Panuco crude oil as determined by the Redwood viscometer at various temperatures:

[28] See *Gulf Coast Oil News*, p. 11, September 22, 1917.
[29] See U. S. Bureau of Mines, Bull. 148, pp. 13, 21, 1917.

At 100° F.	Viscosity	13,920 sec.
110° F.		8,558 sec.
120° F.		5,400 sec.
130° F.		3,645 sec.
140° F.		2,800 sec.
150° F.		2,010 sec.

In other words, a unit quantity of Panuco crude petroleum will flow through the same small aperture in the containing vessel when at a temperature of 150° F. in less than one sixth of the time required when at a temperature of 100° F.[30]

Of much less economic importance because of the remote probability of its occurrence, but still worthy of consideration is the possibility of encountering, in the regions of greatest volcanic activity, heat great enough to convert the underground waters, if present, or surface waters which might be introduced into the borehole, into steam and thus into power. Volcanic heat is at present employed for power production in Italy,[31] and in a region where, with the few wells which have been drilled to the present, underground temperatures of 181° F. have already been encountered, it is not altogether impossible that even greater temperatures will be found in the future.

The author will not attempt to summarize his own conclusions further than to express a belief that continued study of temperatures in the region under discussion and of its detailed geology will result in such knowledge of their variation that estimates regarding the approach of the drill to oil and water-bearing formations of importance, based on temperature observations, will be made in the future with some degree of certainty.

[30] For more complete description of the Redwood viscometer see Holde's "Examination of Hydro-carbon Oils," fourth ed., p. 114, 1915, and for further data re the viscosity of Mexican oils and their relation to temperature see Glazebrook, R. T., W. F. Higgins, and J. R. Pannell, "The Viscosity of Oils in Relation to the Rate of Flow through Pipes," *Jour. Inst. Pet. Technologists*, Vol. II., pp. 45–84, 1916.

[31] *The Popular Mechanics Magazine* for December, 1917, pp. 803–808, contains a description of the Italian plant.

A PEGMATITIC ORIGIN FOR MOLYBDENITE ORES.

E. Thomson.

The greatly increased demand for molybdenum ores, of which molybdenite is by far the most prominent, has rendered the matter of their origin a question of vital interest to prospectors and to investors in this uncertain type of mining property.

As the origin of molybdenite ores has, in general, been conceded to be pegmatitic, the reasons for writing this article may seem somewhat obscure. Nevertheless it has seemed to the writer that, in at least two types of molybdenite deposit herein described, the origin of the ore is uncertain enough to form a basis for discussion.

The material for this article was collected by the writer in Pontiac county, Quebec, and in certain parts of the province of Ontario, while investigating numerous molybdenite properties.

GEOLOGY.

The geological features as described here refer more particularly to the townships of Aldfield, Clarendon, Eardley, Huddersfield, Masham, Onslow, and Thorne in Pontiac county, Quebec, but, as the localities visited in Ontario showed petrographic associations of a similar nature, the same general classification will serve for both. It is as follows:

1. Early Palæozoic—including the Calciferous, Chazy, and Black River formations.

2. Laurentian System—principally granites, granite gneisses, syenites, and syenite gneisses, but including also lesser areas of more basic rocks, such as diorites, diabases, gabbros, amphibolites, pyroxenites, and anorthosites; its later phases characterized by numerous irregular pegmatitic areas as well as pegmatite dikes.

3. Grenville Series—a series of metamorphosed sediments,

principally crystalline limestone and contact pyroxene rock, but including also smaller areas of quartzite, hornblende and biotite schist, and paragneiss.

The oldest rocks in this district are undoubtedly the ancient sediments of the Grenville Series. These were intruded by the rocks of the Laurentian, whose earlier phases were characterized by a digestion process between the limestone of the Grenville Series, and its own granitic magma producing the contact pyroxene rock and various peculiar intermediate rock types. Its later phases were characterized by the production of dikes or irregular masses of pegmatite. By far the greater portion of this district is covered with rocks of the Laurentian System and the Grenville Series and, as these are the principal carriers of molybdenite, these alone will be described in detail.

LAURENTIAN SYSTEM.

The Laurentian consists of igneous intrusions, the more important being granites, granite gneisses, syenites, and syenite gneisses, with lesser areas of more basic rocks. It has been subdivided by some geologists, but, as the geological boundaries between the various members are indistinct and usually show a regular gradation from one to the other, the writer does not consider it advisable to attempt any such subdivision.

The rocks of this system are widespread in their distribution, covering about two thirds of the county of Pontiac. In concession VII. of the township of Onslow in Pontiac county, the granites, syenites, and gneisses frequently show segregations of a slightly more basic character than the surrounding rocks. The segregations are as a rule only a few square feet in area, but occasionally, as at the No. 1 Pit of the Dominion Molybdenite Co.'s Mine near Quyon, are of considerable extent. They frequently carry molybdenite. They will be discussed in more detail in connection with the first type of molybdenite deposit.

Numerous pegmatitic areas are to be found in the granite and syenite rocks of this system, particularly in the southern part of the county of Pontiac. They are generally small in area but

sometimes cover several hundred square feet, and are always irregular in outline.

Cutting the other Laurentian rocks as well as those of the Grenville Series are numerous pegmatite dikes, which vary in character from quartz veins to feldspar dikes. They are undoubtedly younger than the other Laurentian rocks or the rocks of the Grenville Series, but, as it seems extremely likely that they are mere later phases of the Laurentian, they have been included with this system. The similarity in feldspar content between these dikes and the other Laurentian rocks points to a derivation from the same parent magma.

GRENVILLE SERIES.

The Grenville Series of metamorphosed sediments is represented in this district chiefly by a crystalline limestone, somewhat dolomitic in character, and a pyroxene rock, the latter the result of a digestion process between the limestone of this series and the igneous rock of the Laurentian, to which the very appropriate name "contact pyroxenite" has been given by M. E. Wilson of the Canadian Geological Survey.[1] The other members of this series, pink and white quartzites, hornblende and biotite schists, and fine-grained gneisses, are limited in extent in this region. Considerable quantities of phlogopite, muscovite, and graphite are to be found in the limestone, while pyrite, pyrrhotite, and molybdenite are frequently associated with the pyroxene in the contact rock.

The contact between the igneous Laurentian and the limestone of this series has produced many interesting digestion-products, showing all stages from the original igneous rock to the pyroxenite where the process of silicification is complete. In places where the igneous rock preponderated such half-way digestion-products as pyroxene granites or pyroxene syenites are the usual results, while in other localities where the limestone is in larger lenses these stages of incomplete digestion are usually represented by

[1] Wilson, M. E., "Mineral Deposits of the Buckingham Map-Area, Que.," *Transactions of the Canadian Mining Institute*, Vol. XIX., p. 352.

undigested limestone containing some pyroxene, sometimes with titanite, biotite, scapolite, and apatite as well. The molybdenite, as well as the other two sulphides, is intimately associated with the pyroxene, not only in the "contact pyroxenite" but also in these products of incomplete digestion, and this process would appear to have provided a favorable set of circumstances for its deposition.

TYPES OF MOLYBDENITE DEPOSITS.

The molybdenite in this district occurs in three distinct ways, two of them of widespread importance and the other confined to the northern part of the township of Onslow, Pontiac county, Quebec. These three types are:

1. Associated with slightly more basic segregations in the granites, syenites, or gneisses of the Laurentian.

2. In intimate association with pyroxene in the "contact pyroxenite" of the Grenville series, or in the partially digested rock of this process of silicification.

3. In pegmatite dikes.

The first of these types is confined entirely to the township of Onslow, while the latter are to be found in a great many parts of Pontiac county, Quebec, as well as in the adjacent parts of Ontario.

ORIGIN OF THE THREE TYPES.

The main object of this article is to establish a connection between these three types of molybdenite deposit and the pegmatitic phases of the Laurentian granite magma. The third type, the occurrence in pegmatite dikes themselves, requires little or no discussion as the molybdenite appears as an integral part of these dikes and there can be little doubt as to the origin of the ore. Our attention will therefore be confined chiefly to the other two types of deposit, with only a brief description of the third.

First Type.

This type is confined to a comparatively small area and is of purely local importance. Nevertheless, as it presents some interesting problems and is an example of one of the most im-

portant producers in the country, it will be discussed in some detail. The mine of the Dominion Molybdenite Co., near Quyon, in Onslow township, Pontiac county, Quebec, is at present the only producing mine of this type and its No. 1 pit affords the only example of a large deposit of this kind. Numerous other test-pits in this vicinity show some molybdenite in segregations of the same type but of much smaller dimensions. As the petrographic associations are somewhat different at No. 1 pit from those at the smaller test-pits, they will be discussed separately.

At the No. 1 pit of this mine the country rock is a fine-grained biotite hornblende granite, with faint traces of foliation in places. Its feldspar content consists of about equal proportions of orthoclase, plagioclase, and microcline. The large dome-shaped segregation of biotite syenite which forms the ore-rock runs roughly north and south. This dome has been much fractured, not only at the contact with the country rock, but also within its own mass. The areal extent of the dome is small but increased with depth, so that at 50 ft. it covers an area of about 60×130 ft., the long dimension running approximately north and south. Across the southwest corner of the pit a pegmatite dike, 16 ft. wide at its maximum, cuts both the country rock and the dome-like segregation of ore-rock. This dike, which consists chiefly of quartz and a perthitic intergrowth of microcline and plagioclase, is said to have contained a few small flakes of molybdenite near the surface. Associated with the molybdenite in the ore-rock are considerable quantities of fluorite, pyrrhotite, and pyrite, as well as lesser amounts of tourmaline and pyroxene. The presence of so much fluorite, which is a characteristic feature of the pneumatolytic phases of pegmatite activity, would of itself suggest that a pegmatitic agency had been in operation in the immediate vicinity. The presence of an occasional tourmaline crystal seems to corroborate this. The agent itself is seen in the form of a large pegmatite dike cutting both the country rock and the ore body. Small flakes of molybdenite in this dike further indicate its relation to the ore. The intensive fracturing to which the ore-rock has been subjected, combined with the movements con-

temporaneous with or prior to the pegmatite intrusion, would appear to have furnished channels through which the pegmatitic solutions might operate. Finally it is a very significant fact that not only the molybdenite but also the fluorite and tourmaline are confined within the limits of the fractured ore-rock and are not to be found in the more or less undisturbed granite.

Whether the movement or series of movements which resulted in the fracturing of the ore body, leaving the country rock comparatively undisturbed, took place contemporaneously with the pegmatitic intrusion or prior thereto, must remain a matter of conjecture. It seems likely, however, that part at least of this fracturing is due to the difference in composition between the dome-like segregation and the surrounding granite. The ore-rock, being more basic, would solidify first and would be subjected to various strains and stresses due to contraction on cooling, while the surrounding granite was still in a more or less plastic state. This type of fracturing is particularly well shown at the eastern side of this pit, where it forms a definite line of demarcation between the ore-rock and the overlying granite.

The smaller segregations of this type, which may be seen at several small test-pits in this vicinity, are somewhat more basic in character than that at No. 1 pit. They correspond generally to a biotite diorite in composition, the country rock being usually a biotite syenite. No pegmatitic bodies are to be seen at any of these pits nor is there any trace of fluorite or tourmaline. Numerous irregular bodies of pegmatitic granite are, however, included in the granites and syenites of the Laurentian all through this section of the country and, while none of these were encountered in the immediate vicinity of these smaller segregations, it might well be that further development would disclose the presence of similar pegmatite bodies. In any case the very close similarity between these smaller segregations and the large one at No. 1 pit seems to point to a common origin. These smaller segregations have not been fractured to any extent so that the pegmatitic solutions must have had only narrow channels through which to operate. This would account for the relatively small molybdenite content of these bodies.

Second Type.

This type of occurrence is widespread in its distribution. There are two, however, that present to the best possible advantage all the stages of the silicification process involved in the deposition of this type of ore. They are both in the county of Pontiac, Quebec, one in the township of Eardley and the other on the north shore of Squaw Lake in the township of Huddersfield. As the two deposits are almost alike in character, the same discussion will serve for both, and only the Squaw Lake property will be described in detail, as it furnishes one or two extra mineralogical associations which appear to be extra evidences of a pegmatitic origin.

The Squaw Lake property, situated on the northeastern shore of Squaw Lake, shows a confused mass of several small lenses in contact with a hornblende schist or gneiss of the Laurentian. These lenses were originally limestone, but, in contact with the igneous rock magma, have undergone a process of silicification, complete in some cases, partial in others. The resulting rocks grade from the original limestone, of which a few small areas remain, to the "contact pyroxenite." The half-way products resulting from the incomplete stages of this process produce some peculiar rock types. Where the limestone has predominated, at least locally, the resulting rock is a more or less unchanged limestone, with a few scattered crystals of pyroxene, titanite, and mica, sometimes with an occasional apatite crystal. In places where the igneous rock was in greater quantity than the limestone, peculiar rock types such as pyroxene granites, pyroxene syenites, or gabbros appear, generally carrying considerable titanite and scapolite. Associated with the molybdenite in these lenses are considerable quantities of pyrite and pyrrhotite, all three sulphides being in intimate association with the pyroxene. The ore, although sometimes fairly well disseminated through these lenses, commonly runs through them in the form of narrow bands or streaks.

In this locality the only direct evidence of pegmatitic action is to be found in the presence of occasional pegmatite stringers in

the hornblende schist close to the lenses of ore-rock. These are only a few inches in width and can, of course, have had but a very slight effect in the deposition of the ore. Their presence, however, is significant, as they probably represent small outliers from the original pegmatitic bodies. As a rule in this type of deposit no pegmatitic masses are to be seen, so that our theory must necessarily be supported chiefly by indirect evidences. The reasons for this lack of pematitic bodies will be discussed later.

Two notable exceptions to this rule are furnished by the deposit near Mt. St. Patrick, Renfrew county, Ontario, and a mining-claim some distance north of Squaw Lake in unsurveyed land. At both these localities a coarse granite, with a fine graphic intergrowth between the quartz and the feldspar, forms the country rock. This structure is at least suggestive as representing the later activities of the granite magma, but it is to the peculiar, mineralogical associations characteristic of this type of deposit that we must turn for more conclusive, if indirect, evidences of a pegmatitic origin. From the invariable association of the molybdenite with the pyroxene, the conclusion is inevitable that the deposition of the ore is closely connected with the process of silicification resulting from the contact between the acid igneous magma and the limestone lenses of the Grenville Series. This process has been at work all through this part of the country, both in Quebec and Ontario, and in the great majority of cases no sulphides are associated with the pyroxene. It would therefore seem likely that special agencies have been at work where these lenses carry a sulphide content. In this connection the presence of much scapolite associated with the molybdenite serves as a good indirect evidence of the pneumatolytic phases of pegmatitic activity. The scapolite has evidently been formed from the sode-lime feldspars by the addition of chlorine. In fact in one section from Squaw Lake, the process can be seen in a half-completed stage (Plate XXI., *A*). At the mine near Mt. St. Patrick, Renfrew county, Ontario, scapolite occurs in crystals of some size and is abundantly distributed through the ore-rock. Still more striking is the constant association of more

or less titanite with the ore of this type. This appears to be the natural result of a reaction between such minerals as rutile or ilmenite, characteristic features of the pneumatolytic phases of pegmatitic bodies, and the calcium carbonate or calcium magnesium carbonate of the limestone, in conjunction with the silicification process already mentioned. In all of the deposits of this kind, visited by the writer, titanite is present in considerable quantities. At Squaw Lake, where the percentage is sometimes 10 or 15 per cent. of the total mass of the rock, it probably reaches its maximum. It is significant that no titanite is to be found in the lenses barren of any sulphide content. Further indirect evidence of this theory is the fact that the rock in one of the lenses at Squaw Lake, representing an incomplete stage of the silicification process, shows no less than three separate intergrowths between the constituent minerals (Plate XXII., *A, B*). It probably represents the very latest stage of igneous activity when the increasingly acid magma has reached an approximately eutectic composition, the various constituents crystallizing simultaneously. This is a phenomenon characteristic of pegmatites, which represent the latest and most acid phase of the granite magma.

The objection might be raised that, where any comparatively large deposit of this type occurs, some part of the pegmatitic body would remain to bear out this assumption. This, however, could not happen. It is a generally accepted theory that a rock magma consists of a complex solution of silicates and other minerals, on the one hand, and gases on the other, and that between these two there is only a limited mutual solubility in the liquid state, which becomes more limited with declining temperature. In this connection Harker[2] remarks:

> On this supposition, the magma, as it cools, will separate progressively into two partial magmas, one containing most of the silicate and other minerals, and the other with a preponderance of water and other volatile substances. The latter, which we may call the aqueous solution, will collect especially in the marginal parts of an intrusive body, where the cooling and consequent separation begin; but smaller portions may sub-

[2] Harker, A., "History of Igneous Rocks," p. 295.

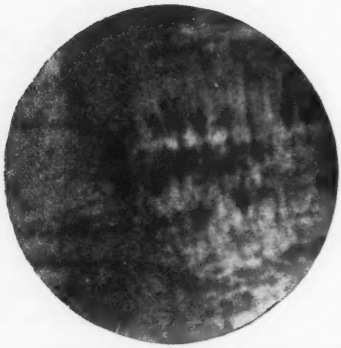

FIG. *A*.

Alteration of plagioclase (*a*) to scapolite (*b*), plagioclase largely kaolinized. Crossed nicols. × 180.

FIG. *B*.

Two intergrowths, one between two feldspars (*a*), and the other and molybdenite, white-scapolite. Natural light. × 20.

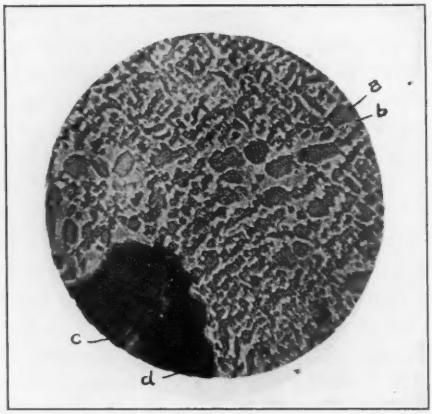

FIG. *A*.

Graphic intergrowth of orthoclase (*a*) and plagioclase (*b*); *c*, pyroxene; *d*, large plagioclase. Crossed nicols. × 180.

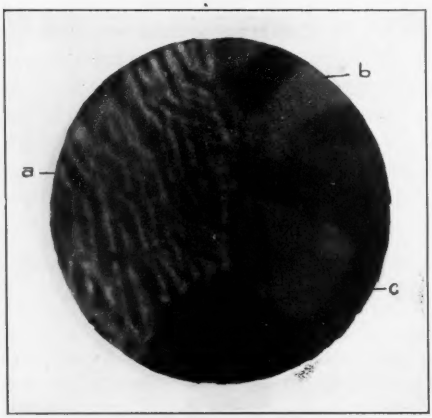

FIG. *B*.

Two intergrowths, one between two feldspars (*a*), and the other between plagioclase (*b*) and pyroxene (*c*). Crossed nicols. × 180.

sequently detach themselves in the interior, giving rise to druses and veins. When the other part of the magma (the silicate solution) has become effectively solid, fissures in it may be injected with the still fluid aqueous solution, the normal plutonic rock thus being traversed by veins, sheets, and strings of pegmatite. Owing to its great fluidity, the aqueous solution may be injected, even in the finest apophyses, into the contiguous sedimentary or other rocks, and may travel to considerable distances from the main body of the intrusion.

Whether the theory of limited mutual solubility between these two parts of the magma be accepted or not, the magma undoubtedly does separate into these two partial magmas, which have conveniently been called the silicate and the aqueous solutions respectively, the latter being, as Harker[3] expresses it, "the residual 'mother-liquor' at the end of the process of crystallization."

In the case under consideration of an acid igneous magma in contact with the limestone, we must assume that the equilibrium between the silicate and the aqueous solutions has been disturbed by the drawing off of the silica from the former in the process of converting the calcium carbonate or calcium magnesium carbonate to the silicate pyroxene. This would leave the silicate solution partially depleted of the material for quartz and feldspars. The aqueous solution, in an attempt to restore this equilibrium, would yield up part of its feldspar and quartz material. This process would continue until the aqueous solution has been entirely deprived of this material, leaving only a concentrated residual mother-liquor rich in sulphides and pneumatolytic minerals. Thus there will be no bodies or dikes of pegmatite left. The fact that the solutions in this type of deposit were heavily concentrated is borne out by the manner of deposition of the sulphides. These follow small cracks and fissures in the pyroxene rock, tracing out in many cases the outlines of the pyroxene and scapolite crystals (Plate XXI, *B*). The chlorine which changes the feldspars to scapolite has also been carried by this concentrated aqueous solution, and furnishes a good example of the destructive phase of pegmatitic action.

In conclusion it seems to the writer that, while direct evidences

[3] Harker, A., "History of Igneous Rocks," p. 296.

are for the most part lacking, there can be little doubt as to the pegmatitic origin of this type of ore.

Third Type.

The best example of this type of molybdenite deposit is to be seen near Plevna, Frontenac county, Ontario. Here the molybdenite is found in a pegmatite dike, about 7 feet wide, cutting a fine-grained Laurentian gneiss. This dike consists chiefly of quartz and feldspar, but contains also some little biotite, muscovite, and pyroxene. The molybdenite appears in the form of small pockets in this dike, the flakes being a fair size in places, and usually in close proximity to the pyroxene. This type of deposit is so well known that it needs no further description. Its origin is of course undoubtedly pegmatitic.

CONCLUSIONS.

It would seem that the fluorite and tourmaline associated with the ore in the first type of deposit, and the scapolite and titanite so prominent in the ore of the second type, might serve as indicators or guides in the hunt for molybdenite ore. Pyroxene is, of course, invariably associated with the molybdenite in the second type of deposit, but it may be noted that there are many more localities where plenty of *contact* pyroxene rock is to be seen without any trace of sulphides whatever. On this account the finding of the contact pyroxene rock is only the first step in the hunt for the ore and, without the location of some such minerals as titanite, scapolite, or the iron sulphides, would be barren of results.

The second type of deposit is the most common and will be the one most often encountered in this part of the country. With this in mind, the prospector should look first of all for the contact pyroxene rock and then for such indirect evidences of the pneumatolytic phases of pegmatitic activity as are furnished by the presence of such minerals as titanite, scapolite, pyrite and pyrrhotite. These two sulphides, which on weathering impart

a dark brown or black color to the rock, giving rise to the local expression "burnt rock," are also useful indicators, as they are constant associates of the molybdenite in this second type of deposit.

This article is published with the permission of the mining syndicate for which the writer worked during the summer of 1917. He is greatly indebted to the members of this syndicate for free access to the petrographic material collected in the field.

DISCUSSION.

This department has been established by the editors in order to afford to those interested in questions relating to economic geology an opportunity for informal discussion. Contributions are cordially invited either in the form of discussion of more formal papers appearing in earlier numbers or bearing upon matters not previously treated. Letters should be directed to the Editor, Sheffield Scientific School of Yale University, New Haven, Conn. The full name of the author should be attached to all communications.

THE GEOLOGIST IN WAR TIMES: RELATION TO MILITARY WATER SUPPLIES.

Sir: Wherever a large number of human beings are assembled there is imperative need for a large and dependable supply of potable water. This supply must be obtained from either surface or ground waters. The problems of locating ground-water supplies are almost wholly problems of geology. Many cities have great difficulty in solving their water-supply problems even though they have attained their population through years of gradual growth. In military preparations, even far behind the line, such as have been made in the United States during recent months, water supplies comparable in quantity and quality to the public supplies of cities must be provided immediately both for human consumption and for numerous industrial purposes. Thus, since this country entered the war the small group of geologists who are especially trained in hydrology have rendered an important service of the most direct and practical kind in the development of water supplies for the numerous cantonments and industrial establishments suddenly brought into existence by the War and Navy departments.

At the front, however, the problems of water supply are much more acute, especially in expeditionary campaigns. The troops have to be moved quickly into new localities, and these new localities must be chosen for strategic reasons often without regard to water supplies, if indeed there is any choice in the matter.

On account of the difficulties of transportation at the front and the danger of having a body of troops separated from a remote base of supplies, it is important to have the source of the water as near as possible to the individual soldiers who depend upon it. Moreover, at the front it may not be possible to sink wells in the localities with the best prospects because these localities may be exposed to the destructive agencies of the enemy. In the campaign of the Allies in the Gallipoli Peninsula water was extremly scarce, much of it being brought in transports from Egypt. According to information that I have obtained, favorable sites for sinking wells were located by geologic methods and some ground water was developed, but the Turkish forces hindered the drilling operations so effectively by gun-fire and by dropping bombs from aëroplanes that the deeper horizons could not be tested in the limited time that was available.

It is an interesting fact that in both Greece and Palestine—countries which have so long been populated by civilized peoples—valuable water supplies, hitherto not known to exist, have been developed by the British forces by sinking wells on the advice of scientists who applied geologic methods. The wells in Greece, in the vicinity of Salonica, were sunk on the advice of A. Beeby Thompson; those in Palestine, on the advice of Aaron Aaronson, the director of the Palestine agricultural experiment station.

If the United States should ever be compelled to fight on its own frontiers the matter of water supplies would be of great importance, especially in the arid Southwest, which in most parts does not contain enough water to sustain any large number of troops but which in certain definite localities has potable underground supplies that would support permanently the largest armies. The War Department, through the Geological Survey, is in possession of much more precise information on this subject than is generally known.

O. E. MEINZER.

THE PETROLOGY OF RESERVOIR ROCKS AND ITS INFLUENCE ON THE ACCUMULATION OF PETROLEUM.[1]

Sir: Mr. A. W. Lauer's paper on the petrology of petroleum reservoir rocks, in the August number of this journal, is a welcome contribution to a subject that has recently received too little attention. Although a large number of geologists are now occupied exclusively with petroleum work their time is so largely taken up with the strictly practical business of "finding oil" that they unfortunately have little time for the investigation of special phases of the subject, and all scientific studies are therefore of particular interest. As Mr. Lauer's conclusions are somewhat revolutionary his paper merits a careful reading.

We younger geologists are perhaps a bit prone to think that all petroleum geology dates from about 1900, and to forget that many of our problems were studied and discussed by the eminent geologists of the West Virginia, Ohio, and Pennsylvania Surveys in the earlier days of the petroleum industry. Mr. Lauer makes the rather sweeping statement that "all discussions of porosity hitherto published have been of too limited a scope and have erred in not sufficiently recognizing the part played by openings of an induced nature." Although he is apparently not aware of the fact, the question as to whether petroleum exists chiefly in interstitial spaces or in supercapillary cracks and fissures, was a live issue thirty or forty years ago. Campbell[2] states that "in the first twenty years of exploration it seems probable that the latter view [that oil occurs only in open fissures] was most commonly held, as it offered an explanation that seemed entirely adequate to account for the phenomenon, whereas the theory of oil accumulating only in the pores of the rock seemed to tax the imagination beyond the limit of probability and consequently was held only by a few men who could realize the possibilities of such an hypothesis." Moreover, for a long time after

[1] Published by permission of the Director U. S. Geological Survey.

[2] Campbell, M. R., "Historical Review of Theories Advanced by American Geologists to Account for the Origin and Accumulation of Oil," ECON. GEOL., Vol. 6, p. 365, 1911.

that period most geologists in referring to the interstitial porosity of reservoir rocks qualified their remarks by alluding also to fissures and crevices. The best authorities finally concluded, however, that interstitial space or "original porosity," as Mr. Lauer terms it, is far more important than the cracks, fissures, or other openings, which he includes under the heading "Induced Porosity." The discussion being apparently satisfactorily closed, the question dropped out of the current literature and all recent articles on porosity have dealt almost exclusively with interstitial porosity. In so far as the most recent literature is concerned, then the author's statement is correct; and as many important fields have come into existence since the earlier discussion of the subject, it is doubtless appropriate that the question be reopened at the present time.

Mr. Lauer's main thesis is that induced porosity is enormously important in oil accumulation, and that "it entirely overshadows the original porosity of an interstitial nature, except in the case of loosely consolidated sands." As most of the openings considered are supercapillary in size he concludes that the circulation of oil and water is governed by hydrostatic laws and that this fact serves "to reëstablish the anticlinal theory." He supports his thesis by evidence derived from a microscopic examination of specimens of reservoir rock from the principal North American fields and discusses the subject in the light of the researches of students of ore deposits. A subsidiary argument is that estimates of oil production based upon computations of the original porosity of the reservoir rocks are usually wide of the mark, and that the discrepancy is due to the great and hitherto unrecognized part played by induced porosity.

Before presenting his evidence Mr. Lauer gives a review of the "theories of oil movement and accumulation now in the literature." Those considered are the anticlinal theory, as stated by Griswald and Munn; the hydraulic theory formulated by Munn; the theory of capillary concentration, proposed by Washburne; the theory of selective segregation and gravitational separation advanced by Johnson and Huntley; and the filtration theory of Day.

It is unfortunate that the author has treated these as distinct and conflicting theories, rather than as more or less harmonious attempts to explain several different sets of phenomena. In the first place the anticlinal theory in its original form simply held that gas and oil occur chiefly on anticlines and water chiefly in synclines, and this has been so abundantly confirmed that it may now be regarded as a principle, rather than as a theory. In seeking to explain these phenomena it is natural that the marked difference in specific gravity between oil and gas and water should first be appealed to, and thus there arose what Mr. Lauer evidently regards as the anticlinal theory, but what is more strictly the theory of gravitational transportation and separation brought about by hydrostatic pressure. As data multiplied concerning the structural relations of oil pools it was found that pools do not occur solely on the axes of anticlines, even in saturated rocks; and it was felt also that the theory of gravitational separation did not adequately explain the cause of gas pressure. Munn found by experiment that oil, gas, and water in the pores of a sand show no marked tendency to adjust themselves in layers unless the fluids are moving, and he therefore introduced the idea of movement or separation through hydraulic or capillary, rather than hydrostatic pressure. This conception is a step in advance, in that it takes account of the movement of ground water, which helps explain the occurrence of oil or gas pools under certain structural conditions. Munn also pointed out the important rôle of capillarity in sealing the pores of rocks and making them inpervious, which furnishes an explanation of the retention of gas pressure, though not of its origin. This, however, is simply a corollary of his main contribution—that the separation of oil, gas, and water is facilitated by movement, and that their accumulation is effected by the movements of the ground waters. This is not opposed to the anticlinal principle, but, on the contrary, broadens it and helps to explain it; in fact it is not wholly incompatible with the theory of separation by gravity under simple hydrostatic pressure.

The other theories listed by Mr. Lauer are also simply attempts

to explain certain phases of oil accumulation or point out the importance of certain causes which hitherto had not been fully recognized. Thus Washburne advanced his capillary concentration theory chiefly to explain why gas and oil are usually found in sand instead of in shale, though he discusses the bearing of the principles advanced on the migration of oil and on its anticlinal distribution. Similarly Johnson and Huntley accept Munn's conception of gravitational separation through movement and Washburne's theory of capillary concentration, and they also lay emphasis upon the immiscibility and relative viscosity of oil, gas, and water. Their "theory" incorporates the best points of the older views and is therefore a step in advance, but only to this extent is it distinct from them. Day's work on the fractionation of oil by diffusion through fuller's earth helps to explain an entirely distinct phenomenon—the difference in the character of oil in different fields—but it has only the remotest bearing on the mechanical accumulation of oil in pools, and its treatment as a theory coördinate with the "anticlinal theory" seems a trifle absurd. Mr. Lauer might better have discussed Daly's Diastrophic theory,[3] which has several good points; or, if he wished to introduce the unrelated subject of the character of the oil, should have included David White's[4] work on the dynamic alteration of petroleum.

Passing to the main subject of the paper, Mr. Lauer bases his argument in favor of the importance of induced porosity partly on a personal examination of a number of samples of reservoir rock and partly on quasi-theoretical considerations drawn principally from text-books on ore deposits. In other words he compiles, largely from the literature of ore deposits, a list of the different classes of openings that can exist in rocks, and considers his own evidence in the light of this compilation. After sifting the original evidence presented it appears to me that Mr. Lauer has been unduly impressed by the length of this list and that he

[3] Daly, Marcel R., "The Diastrophic Theory," *Am. Inst. Min. Eng. Bull.*, No. 115, p. 1137, 1916.

[4] White, David, "Some Relations in Origin between Coal and Petroleum." *Washington Acad. Sci. Jour.* (March 19, 1915), Vol. 5, No. 6, p. 189.

has based his conclusions more upon the fact that many different types of openings *may* occur, than upon any direct evidence that they do actually occur to any extent in reservoir rocks.

Mr. Lauer's list of induced openings may be epitomized as follows: Fissures due to faulting, to brecciation, to jointing, and to torsional stresses; cavities due to dolomitization and to solution; and porosity due to former surface weathering below unconformities. The reference to porosity due to former surface weathering is novel, interesting, and suggestive. However, the beds beneath the Mississippian-Devonian unconformity in the Appalachian field, the Pennsylvanian-Ordovician unconformity in Oklahoma, and the inter-Tertiary unconformities in the California fields are either only slightly productive or are barren, so that the suggestion seems to have little practical significance. The importance of cavities due to dolomitization or solution is generally admitted and was recognized by Orton many years ago in the old Trenton limestone field. Such cavities are important also at Spindletop and in several neighboring fields on the Gulf Coast in which the oil is derived chiefly from a limestone cap rock; and in those Mexican fields in which the oil is derived from the porous or cavernous Tamosopo limestone. Such cavities can of course be of little or no importance in the sandstone fields from which the very great bulk of the present production of the United States is derived; in these fields the induced openings must be those due to faulting, brecciation, jointing, etc. In three fields of very minor importance the oil is known to occur in such fissures, viz., in the Florence, Colo., field in shale, in the Thrall, Tex., field in serpentine, and in part of the Santa Maria, Cal., field in flinty shale. Admitting the importance of solution and dolomitization cavities in the limestone fields, and of fissures in a few other fields which have more scientific interest than practical value, Mr. Lauer's main contention, that cracks and fissures "entirely overshadow the original porosity except in the case of loosely consolidated sands," remains to be examined.

The evidence gathered by specialists in one branch of the science is often of interest and value to those in an entirely different branch, but it is essential to realize that facts of prime im-

portance in the deposition of ore deposits are not of prime importance in the accumulation of petroleum. Students of ore deposits recognized long ago that metalliferous solutions tend to migrate through, and to deposit in, fairly open channels, and they have therefore paid special attention to all possible types of supercapillary openings and the conditions which give rise to them. As their work lies chiefly in more or less disturbed regions, in which igneous action has usually been effective, they have had no difficulty in distinguishing several types of fractures due to earth movement, or in demonstrating the importance of such factors in connection with the deposition of ores. To infer, however, without further evidence, that such fractures are of similar importance in connection with the accumulation of petroleum is to overlook the fact that petroleum occurs characteristically in strata but slightly disturbed. The most highly disturbed fields in the country are the California fields; and the great bulk of the large production of those fields is derived from unconsolidated sands, in which Mr. Lauer himself admits that induced porosity can be of little or no importance. Mr. Lauer's list of rock openings will be welcomed by petroleum geologists as an instructive and suggestive compilation of possibilities, but his argument for induced porosity must stand or fall upon his own concrete evidence.

In his description of the specimens examined, Mr. Lauer lists five under the heading "Original Porosity," six under "Induced Porosity," and five under "Original and Induced Porosity." Of the first class three are from Oklahoma, one from Illinois, and one from California. Of the second class one is a specimen of the Berea from Ohio, one is from Oklahoma, and four are from California; all of these rocks are described as "tight and well cemented." Mr. Lauer makes no mention whatsoever of finding cracks or other openings either in the thin sections or in the specimens (some of which he says are as large as 9 inches in length), or even of observing veins which would represent former cracks; he observes that the rock is "tight," and simply infers that the oil must therefore occur in fissures. The same reasoning is applied to the five specimens of an intermediate type, of which one is from Wyoming and four are from Oklahoma.

Without desiring to impugn the "origin and genuineness" of the author's specimens, I may point out that a single specimen may not be representative of the sand as a whole. This is well illustrated by the author's California specimens, four of which are listed under "Induced Porosity," notwithstanding the fact that the California fields as a whole are almost unique (in this country) in the looseness of the oil sand. I have seen a few specimens of fairly well cemented sands from the California fields, but I should say that 95 per cent. of the oil produced in California is obtained from sand so loose that it may be brought up with the fluid. I therefore can not admit that any weight should be attached to the evidence of four of the author's six exhibits. A factor that may injure the character of the other two specimens is that if the sand is variable in porosity an unusually coherent or well-cemented fragment is more likely to be brought to the surface as a unit than is a friable piece, especially if the fragment is shot from the well.

Furthermore, it is possible that if the author had actually tested the interstitial porosity of the well-cemented piece of Berea sandstone he would have found it to be much higher than he supposed. Bownocker[5] cites six tests of the porosity of the Berea grit, which gave results ranging only between 15.87 and 17.83 per cent. If Mr. Lauer's specimen is really much less porous than this it appears that the difference must be due to local variation in porosity. Furthermore, is it not possible that some of the calcite cementation described is comparatively recent and occurred after the migration of the oil to its present position? Mills, Wells, and Goldman[6] have presented evidence indicating that cementation in the Appalachian fields is to some extent related to the circulation of the ground waters occasioned by drilling, and that some of it at least was effected after the field was opened up.

Mr. Lauer's original evidence is therefore not very convincing, and it is opposed by several general but well-founded considerations. In the first place if the beds are as fissured as the

[5] Bownocker, J. A., "Building Stones of Ohio," Ohio State Geol. Survey Bull. 18, 4th ser., p. 77, 1915.

[6] *Washington Acad. Sci. Jour.*, Vol. 7, No. 10, p. 309, May 19, 1917.

author supposes, it is difficult to understand how oil is retained in the reservoir and why it does not migrate up across the strata. As a matter of fact when fissuring is extensive enough to play much part, practical experience dictates that the district should be condemned; and the fact that such districts are usually characterized by an abundance of seeps is regarded simply as evidence that most of the oil has escaped to the surface. Again, all oil men recognize the existence of pay streaks, and it is common knowledge that their productivity is due to the fact that they are the most open and porous parts of the sand. If the sand were traversed by a multitude of open cracks the greatest accumulation of oil would be expected at the top of the stratum, irrespective of differences in the interstitial porosity. Another well-known feature of oil sands is the presence of shale partings or "breaks," which, though only a few inches thick, may render communication between different layers of the sand impossible, as shown by enormous differences in gas pressure. Not only are pay streaks recognized in all fields, but some fields may, themselves, be regarded as great pay streaks. The most striking example in my own experience is the Cleveland gas field of Ohio. The distribution of the gas, which occurs in the fine-grained Clinton sand, is affected in a broad way by structure, but in detail is apparently controlled entirely by the porosity of the sand. Where the sand is tightly cemented or clayey, little or no production is obtained, and this condition seems also to apply in the other Clinton gas fields farther south. This would obviously not be the case if induced porosity were an important factor, and as the Clinton sand is coherent enough to shatter readily under strain it might be expected to offer an excellent illustration of Mr. Lauer's contention. References to variation in productivity in other fields, due to variation in porosity, are so widely scattered through the literature that they need not be recalled here.

One other broad consideration may be worth noting—the very widespread occurrence of petroleum in quartz sand. On this continent the only important exceptions are the Tamosopo limestone field of Mexico, the old Trenton limestone field, and some of the pools in Kentucky and Tennessee. If induced openings of

the types discussed by the author were of much importance we should expect to find petroleum in igneous or metamorphic rocks wherever they occurred in the neighborhood of a source rock of petroleum. We should certainly expect to find it more commonly in such shales as are hard enough to stand fracturing and also in the cracks and fissures (not only solution cavities) of limestones. Unless we postulate a special affinity between petroleum and quartz we must admit that the occurrence of oil in quartz sand is due to the latter's distinctive feature, its high interstitial porosity.

A minor argument of a different nature advanced by the author as supporting the importance of induced porosity is that estimates of oil production based on computations of interstitial porosity have proved inaccurate. Admitting the truth of this statement, I think it more reasonable to suppose that the discrepancy is largely due to the fact that only a fraction of the oil is recovered. Furthermore, in most fields no records of the production of gas are kept, yet the space occupied by one barrel of oil would hold 337 cubic feet of gas under a rock pressure of 900 pounds, and a gasser making 3⅓ million cubic feet would theoretically relieve as much space as a 10,000 barrel well.[7] When we consider, furthermore, the difficulties in the way of making anything like an accurate estimate of the average porosity of the oil sand or even of its thickness, the fact that such estimates are often greatly in error is not to be wondered at.

I have discussed Mr. Lauer's paper at some length because of the far-reaching character of his conclusions, and because of their significance if correct. The predominating importance of open cavities in most limestone reservoirs is generally recognized, and I think most petroleum geologists will admit that fissures and other openings of an induced nature occur to some extent in most fields. I can not see, however, that Mr. Lauer has advanced any new evidence to prove "the enormous importance of induced porosity," and feel that such a conclusion is directly opposed by many well-founded observations.

G. SHERBURNE ROGERS.

[7] These computations were made by Carll and are approximately correct.

REVIEWS.

The Principles of Economic Geology. By WILLIAM HARVEY EMMONS. McGraw-Hill Book Company, Inc., 1918.

The science of economic geology in its present-day aspects is extremely young, and consequently its growth is fast and its changes rapid. It is nevertheless something of a surprise to find the same publishers issuing a new treatise on the subject only five years after the appearance of Lindgren's "Mineral Deposits." An examination of the contents of the new volume indicates that its purpose is not to incorporate the results of a marked advance in the science during the interval, but rather to present the subject from an entirely new standpoint. The merit of the volume is to be sought and weighed not so much in its contents as in the manner of their presentation.

The book is intended to serve as a text-book of economic geology for advanced students, and the method of presentation of the subject adapts it admirably for such use. The preface states that it is an expanded series of lectures on economic geology which the author has offered for a number of years. In geographic range it is intended essentially for a North American *clientele*, illustrations and descriptions of mining districts being confined largely to those of this continent and more particularly of the United States. A number of the more important and widely known foreign occurrences, however, are also included among the districts used for illustrative purposes.

Though its major divisions are consecutively numbered chapters, the book in reality consists of two distinct parts. The first part, the first twenty-one chapters, embracing two hundred and eighty-nine pages, is a discussion of the principles of economic geology. The second part, chapters twenty-two to twenty-eight and embracing two hundred and ninety-nine pages, is chiefly a description of the mineral deposits of the United States, both metallic and non-metallic.

The first part of the book in which the principles of economic geology are set forth is naturally the one of greatest interest to the student of the subject. The twenty-one subjects considered are presented in a concise yet thorough manner. A brief introductory chapter is devoted to definitions, among which *ore* is defined as "a mineral or association of minerals that may, under favorable conditions, be worked commercially

for the extraction of one or more metals," and *protore* as "low-grade metalliferous material which is not itself valuable but from which valuable ore may be formed by superficial alteration and enrichment." This distinction should satisfy those who insist on an economic definition of ore.

The author recognizes three factors in establishing a classification of ore deposits: (1) deposition, (2) deformation, (3) superficial alteration and enrichment of the deposits. Deposition involves the primary mineralization and includes eight commonly recognized genetic types. These are: (1) magmatic segregations, (2) pegmatite veins, (3) contact-metamorphic deposits, (4) deposits of the deep vein zone, (5) deposits formed at moderate depth by hot solutions, (6) deposits formed at shaldow depth by hot solutions, (7) deposits formed by cold solutions, (8) sedimentary deposits. Deformation affects the primary deposits through faulting, folding, or dynamic metamorphism. Enrichment of the undisturbed or the deformed primary deposits may take place either through the removal of valueless material, or by solution and redeposition of valuable constituents. These various processes and the types of ore deposits to which they have given rise are discussed in chapters three to fifteen, with the exception of chapter eleven, interpolated at the end of the eight chapters dealing with the types of primary ore deposits, which treats of primary ore shoots. A diagrammatic representation of the mutual relationships of these processes presents a very helpful picture. The arrangement herein adopted gives a more definite recognition of deformation and enrichment as processes forming characteristic and distinct types of ore deposits than does the usual method of arrangement of classification, which is more apt to lead one to look upon the primary mode of deposition as the sole factor in classification, and to regard deformation and enrichment merely as processes effecting later changes in the primary types.

The eight chapters dealing with the primary deposits follow a common plan. Five topics are considered: occurrence, composition, shape, size, and texture. An introduction in smaller type gives a summary statement under these topics. The body of the chapter contains an amplification of the same topics and additional topics are introduced to fit the particular requirements of the type of deposit under consideration. Thus under pegmatites, eutectics are defined, and agents of mineralization, gradations of pegmatites into veins and the temperature of their formation are discussed. A few typical deposits of each type are referred to for purposes of illustration. At the end of each chapter is a selected list of references which can be used if desired for a more detailed study of its subject-matter.

A close adherence to the conception of magmatic segregations which

is due so largely to the work of Vogt, according to which they represent but a phase of normal rock differentiation, is indicated by the statement that "the deposits are therefore igneous rocks in a strict sense." The principal example cited is the Sudbury district. One is surprised not to find a modified conception in line with the recent work of Tolman and Rogers and of others who have studied the Sudbury ores, particularly in view of the prominent use of Sudbury as an example of magmatic segregation. The old conception was so simple, and Sudbury seemed to illustrate it so well, that one gives it up with reluctance and clings to Sudbury as a typical example perhaps longer than is justified. In fairness the reviewer should admit that he is himself guilty of this in his own lectures. But in a lecture one can gracefully use an illustration and at the same time call attention to the fact that after all the illustration may not be an example of what it is intended to illustrate, a procedure that is not good form in a printed text-book. For that reason one can escape loud protests by the avoidance of the Sudbury deposits as an example, if he is not prepared to accept, or at least accord recognition, to the prominent rôle that mineralizers seem to have played in the genesis of such sulphide deposits as those of Sudbury, a rôle far greater than they are commonly believed to have played in rock differentiation in the normal petrographic sense. Magmatic segregations as here defined are identical with *gites de ségrégation* of De Launay. The latter recognizes another group which he calls *gites de départ immédiat ou de ségrégation périphérique sulfurée*, or peripheral sulphide deposits, in the formation of which he believes mineralizers to have played a more prominent and active part than in the preceding and to have been present in such abundance that they were just on the threshold of carrying the metals beyond the magmatic stage before their deposition. He includes Sudbury in this type. If mineralizers have played so prominent a rôle in the formation of deposits of the Sudbury type, it is evident that the author's definition of magmatic segregations is too narrow to include all of the deposits he puts in that category. Evidence is accumulating to force a modification of the conception of magmatic segregations as herein set forth, which must be met either by broadening the definition or by accepting the new type proposed by De Launay. Graton favors the latter alternative and suggests the very compact, descriptive name *pneumo-tectic* for the type.

The definition or description of contact metamorphic deposits is too strictly in conformity with the schematic conception and does not emphasize sufficiently the large-scale endomorphism that sometimes accompanies exomorphism during contact metamorphism. Endomorphic changes are recognized in a brief paragraph at the end of the chapter, but in such a way as to leave the impression that they are occasional

minor accompanying phenomena of the more common expression of contact metamorphic action, and not that in some instances they are manifested on a large scale. It is unfortunate in this connection that the extensive metamorphism of the igneous rocks at Velardeña was not cited in the paragraph on endomorphic changes, instead of in an earlier paragraph as an exception to the statement that "where igneous rocks are intruded extensive garnet zones are rarely developed," for according to Spurr's description these metamorphosed igneous rocks are the intruding rocks in a limestone series and their extensive metamorphism is endomorphic along their contacts. The alteration of the iron-bearing formation on the Mesabi range by the intrusive gabbro whereby the iron carbonate and greenalite rock has been changed to a magnetite rock of essentially the same chemical composition affords an example of a contact metamorphosed deposit rather than a contact metamorphic deposit, and hence should have been used as an example of deformation and not of a process of deposition to conform to the author's classification of ore deposits.

The classification of hydrothermal deposits into three classes based on the depth at which ore deposition took place is the most satisfactory genetic division of this great group of deposits to which nearly all veins belong. The characteristics of the three types are determined by the temperature and pressure under which mineralization took place. Lindgren first called attention to the characteristic minerals of these types and used them to make the threefold division in his Mineral Deposits. The idea was further developed by Emmons a little later and is now incorporated in his book. He is more conservative in his application of it, in that he does not state limits of temperature and pressure for the divisions in figures, but makes the division a relative one, his attitude being that there is little exact information as to the actual temperature and pressure prevailing at the time the deposits were formed. This basis leads to a more logical classification of veins in a subsequent chapter than one based on temperature alone or on the spacial relation between the igneous rock and the locus of mineralization. It places cassiterite veins and cinnabar veins toward opposite ends of the series, whereas Beyschlag, Krusch and Vogt, for instance, place the cinnabar veins immediately after the tin veins. Its merits over a classification of veins according as they contain oxidic ores or sulphidic ores, which leads Beck to follow a group containing siderite veins with tin veins, are obvious. Spurr has likewise recognized a succession of vertical zones of ore deposition marked by characteristic mineral associations. He regards them as representing the last stages of magmatic segregation and to be functions primarily of temperature. Though the results are somewhat similar, his line of reasoning involves so much that is uncertain

and theoretical that the more empirical basis of division adopted by Emmons is the more acceptable for the present.

In the chapter on deposits of the deep-vein zone, it is stated that deposits of this group are found "in or associated with Mesozoic and early Tertiary intrusive rocks, more commonly than with the middle and late Tertiary intrusives, which in few places have been eroded deeply enough to expose such deposits." No exception can be taken to the statement of fact, but the reason is open to a different interpretation from the one given. Is not the absence of deposits of the deep-vein zone in association with the younger intrusives due to the fact that they were intruded higher than the horizon at which deposits of that zone are formed and that consequently ore deposition took place at a higher horizon than the deep-vein zone? In other words, deep-vein-zone deposits were not formed in connection with these intrusives, and deeper erosion of them would encounter only the roots of the deposits now exposed and still deeper erosion get below the horizon at which ore deposition occurred. There are doubtless late Tertiary intrusives that were not intruded higher than the deep-vein zone and with which deep-vein-zone deposits are associated, but as a rule, erosion has not yet been sufficient to expose these intrusives and their associated deposits. The point the reviewer wishes to make is that deep-vein-zone deposits are formed only in association with intrusives that have solidified in the deep-vein zone, and that deep-vein-zone mineralization has not taken place when the intrusive has been injected to shallower horizons. The objection to Emmons's explanation and the probability of this alternative one are based on the principle which Steinmann enunciated concerning the relation of the metalliferous veins of the Andes and the eruptive rocks with which they are associated, and which a few years later B. S. Butler worked out from a study of the relation of the ore deposits to different types of intrusive bodies in Utah. Butler found that mineralization is associated with the apices of stocks and that deeply eroded stocks are but "remnants from which the portion in which the metals were concentrated has been eroded." If this principle is valid, then deeper erosion of the late Tertiary intrusives with which moderate or shallow depth deposits are associated would not reveal deep-zone deposits, but a horizon below that at which mineralization occurred in association with the intrusives in question. These remarks apply, of course, only to those deposits formed by magmatic waters, but they are now believed to include nearly all hydrothermal deposits.

At the end of the eight chapters dealing with the types of primary deposits is a diagram on which the relative abundance of the various classes of primary ores is indicated for each metal. Several diagrams of this type constitute one of the meritorious features of the book from a text-book standpoint.

The remaining chapters of the group dealing with the types of deposits established in the classification are on deformation of deposits, faulting and folding of ore deposits, dynamic metamorphism of ore deposits, and superficial alteration and enrichment of ore deposits respectively. As would be expected from the importance of the subject and the author's identification with its development, the last-named chapter is the longest of those dealing with the principles, covering forty-six pages. It is an excellent summary of his bulletin on the enrichment of ore deposits. Toward the end of the chapter is a diagram showing for each metal the relative importance of primary ores, ores enriched by subtraction of other material, and ores enriched by redeposition.

The next two chapters deal with openings in rocks. In the first, openings are classified with respect to their origin, and the nature and mode of formation of the various classes described. The second considers openings from the standpoint of loci of ore deposition, and defines the kinds of openings in which vein and other cavity fillings occur, and the manner in which they are frequently grouped. The final section of this chapter on the topographic expression of deposits is rather an extraneous appendage which belongs more appropriately in the chapter on superficial alteration. In the next chapter metasomatic processes are briefly but comprehensively considered. The section on the mechanism of replacement is especially good.

A chapter on mineral associations in veins and wall-rock alterations classifies the common vein types according to their occurrence in the three-vein zones, indicating those that lap over more than one zone. The types are described together with the wall-rock alterations characteristic of them, largely by means of examples of their occurrence in representative mining districts. The Bolivian tin veins, which rank first among tin veins in economic importance, are left out of consideration in the section on cassiterite veins, which doubtless accounts for the latter being classed as solely deep-zone deposits. The features of the Bolivian veins predicate a wider range for the cassiterite veins and make it necessary to extend them at least into the zone of moderate depth. This chapter presents a departure in the use of examples from the plan followed in those that precede. Instead of merely referring to or even describing the features they are intended to illustrate, a more or less complete description of the deposits used as examples is given, and as most of these districts are again taken up in the descriptive part of the book there is considerable repetition. The mere fact of repetition is no serious objection as it involves only a few extra pages of printing. A more serious drawback which this has entailed is a lack of completeness in the description of those districts in the second part. Many data given in this chapter are not repeated in the later one, and vice versa, so that

although these deposits are twice described, neither description is complete in itself. In some instances, as for example Nevada City and Grass Valley, the description given at this point is to be preferred to the one in the descriptive chapter. In other instances, as for example Butte, the description of the mineralization would have been clearer if some of the unrepeated data in this chapter had been used. The figure from Sales illustrating the general distribution of the ore types at Butte would have materially added to the clarity of the description of that district. It would have been better to have kept in mind the features that these districts are intended to illustrate in writing their description and to have confined the description of the vein types to their general characteristics and referred to the districts as examples.

The chapter on metallogenic provinces and metallogenic epochs is so brief as to do little more than define the terms.

The final chapter concerned with the principles of economic geology is on the composition and sources of ascending thermal metalliferous waters. This is a very convincing argument on behalf of the magmatic origin of the greater part of thermal waters that have been effective in ore deposition.

The remainder of the book, chapters twenty-two to twenty-eight, is devoted to the description of the principal mineral deposits of the United States, a number of the Canadian occurrences, and a few unusual ones in other continents illustrating substances not well represented among our own deposits. All but the last chapter are on metalliferous deposits. Instead of following the usual custom of arranging the deposits by genetic types, the author has devoted a chapter each to iron, gold, silver, copper, lead and zinc, and miscellaneous metalliferous deposits respectively. At one time the reviewer would have been inclined to criticize this arrangement as too unscientific for a work of this character, but he is now convinced it is the only practicable way in which to convey to the student a clear idea of the distribution and occurrence of ore deposits. To sandwich the descriptions of mining districts arranged according to genetic types in the discussion of the principles of the subject, obscures the student's conception of the principles themselves and their relations, and leaves him with but a hazy impression of the mineralization and its distribution in the regions that have been described. The plan adopted by Emmons of giving a concise presentation of the principles of economic geology in which mining districts are freely cited as examples, and following it with a description of deposits arranged by metals, yields, in the experience of the reviewer, the best results from a pedagogic standpoint. The sequence in which the metals are taken up in the chapter on miscellaneous metalliferous deposits is apparently as fortuitous as in the volumes on the Mineral Resources of United States.

An alphabetic arrangement would be natural and would present a more orderly appearance. The same remarks apply to the arrangement of the chapter on deposits of the non-metals.

Though two hundred and forty-three pages are devoted to the description of ore deposits, only fifty-six pages are given to the description of the non-metals. There is even a greater disparity in the relative attention accorded the two groups of deposits than indicated by these figures, as the citations of examples in the first half of the volume are almost exclusively to ore deposits. The difference in the weights accorded the two groups is not in harmony with their relative economic importance, or their relative technical value, or their relative scientific interest. It is an indication that a suitable mode of treatment for ore deposits is not adapted to an adequate treatment of the non-metallics when the space available is limited to a single volume. A three-volume treatise with over twenty-five hundred pages, as De Launay's, affords ample space for both. Lindgren, taking the position that a separation of the two groups is "a line of division which can hardly be defended except on the ground of long-established habit," hardly did justice to the non-metallics in his Mineral Deposits, and in this volume they are slighted to a much greater extent. Is this not evidence that a separate treatment is justified on some grounds other than habit, that there are reasons for the habit? One very obvious reason is that it leads to a more balanced result. The reviewer ventures the opinion that the value of this volume would not have been appreciably diminished if the last chapter had been omitted and the title changed to "The Principles of Ore Deposits." This position is taken more particularly with regard to advanced treatises; it is granted that there is a legitimate demand for a brief treatment of the whole range of mineral deposits to serve as a text-book for more elementary courses in economic geology.

The author has plainly kept the purpose of the book in mind throughout its preparation. The treatment of each subject is direct, concise and thorough. Maps, cross sections and other illustrations are used wherever conducive to clearness. The book can be adjusted to fit a wide range in the time available for a course in which it is used. "The descriptions of mining districts are arranged so that some of them may be omitted in classroom work when that seems desirable," and in this way the time required to cover the course may be materially shortened. The abundant references to the literature facilitate expansion at will when time is available for more detailed study. What higher compliment can be paid an advanced text-book than to say it is distinctly *usable* in the classroom or by the student working alone, for so few measure up to that requirement!

JOSEPH T. SINGEWALD, JR.

SCIENTIFIC NOTES AND NEWS

ALBERT BURCH is examining manganese supplies in the West Indies for the U. S. Bureau of Mines.

POPE YEATMAN has been commissioned lieutenant-colonel in the Engineer's Corps of the National Army.

PROFESSOR KEMP has recently returned from Butte to his headquarters at Tulsa, Oklahoma.

D. C. BARD has returned to Seattle from Alaska.

HANZO MURAKAMI, geologist of the South Manchurian Railway, is in Utah studying American mining methods.

LAWRENCE MARTIN, Captain, National Army, and associate professor of physiography and geography at the University of Wisconsin, is on duty in the Military Intelligence Section, War College Division, Office of the Chief of Staff, War Department, Washington, D. C. He has charge of the maps in the offices of the War Council and of the Chief of Staff, and does geographical work for the General Staff in the combat branch of the Intelligence Service.

EDMUND OTIS HOVEY, curator of geology in the American Museum of Natural History, recently gave a lecture in New Haven and at Mount Holyoke College, on the subject, "Two years' experience in the Arctic, with the Crocker Land Expedition."

AT A MEETING held on March 19, the Academy of Natural Sciences of Philadelphia elected as correspondents John H. Comstock, Herbert S. Jennings, Frank R. Lillie, Alfred G. Mayer, John C. Merriam, George H. Parker and Charles R. Van Hise.

W. W. WATTS, professor of geology at the Imperial College of Science and Technology, has been elected a member of the Athenæum Club, London.

HORACE V. WINCHELL is in Salt Lake City.

H. FOSTER BAIN, who during the past two years has been engaged in professional work in China, has accepted the assistant directorship of the U. S. Bureau of Mines, and is now in Washington.

W. G. MILLER, of Toronto, has been appointed Canada's representative on the Imperial Mineral Resources Bureau, London. This board will consist of representatives of the five dominions, of India, the Crown Colonies, and of the mother country, making a total in all of fourteen.

THE MASSACHUSETTS INSTITUTE OF TECHNOLOGY is to be open for the summer months in order to speed up the graduation of the present undergraduate body.

WALDEMAR LINDGREN will be in Cambridge during the greater part of the summer, and will present his geological courses to the summer students of the Massachusetts Institute of Technology.

L. D. RICKETTS was at Ajo this week.

WALTER HARVEY WEED is in San Francisco on his way from Arizona to Montana.

EDWARD H. PERRY, recently of the "Secondary Enrichment Investigation," has been killed in action.

E. DEGOLYER has returned to New York from Mexico.

DR. C. R. KEYES, a well-known geologist of Iowa, is a candidate for the United States senatorship in opposition to Senator Kenyon.

W. G. MATTESON has resigned as geologist of the Texas Company and has opened an office as consulting petroleum geologist at the Texas State Bank Bldg., Ft. Worth, Texas.

JOHN LYON RICH, of the department of geology at the University of Illinois, has been commissioned a captain in the National Army. He is assigned to Washington, D. C., for service in the Intelligence Branch of the Army as a specialist in geography.

J. B. TYRRELL has been spending a few weeks in Tulsa, Oklahoma.

Mr. A. A. HASSAN has been compelled to close the Great Falls Mine, Montgomery County, Md., for an indefinite period, on account of shortage of machinery, miners and coal.

By mistake, in the last number of the journal, the initials of Mr. Hassan were referred to as "H. H." instead of "A. A."